The D_z Project

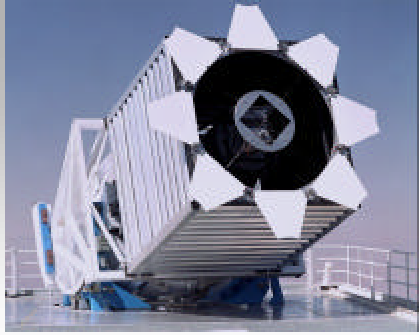
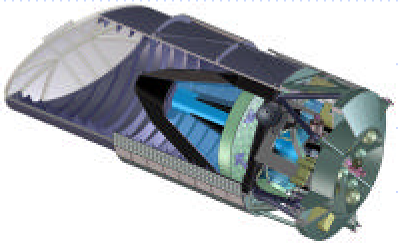
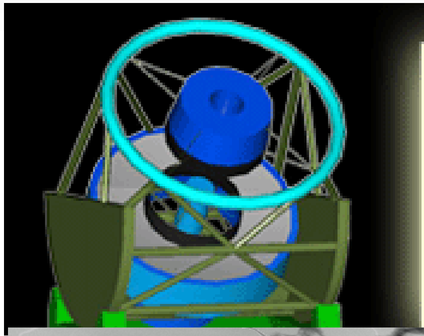
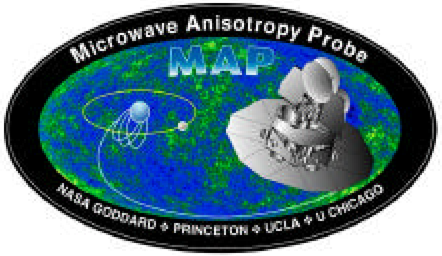
(or is it the Dark Energy Survey?)
(perhaps HIDEOUS?)
(....?)

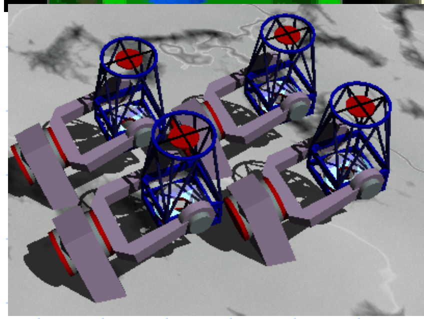
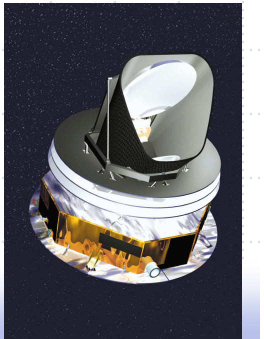
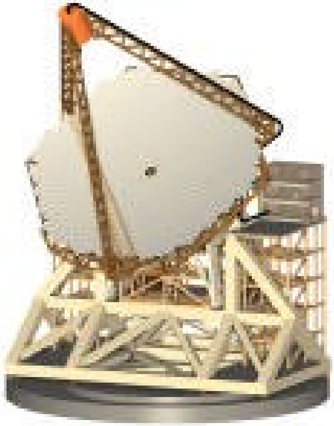
James Annis
Experimental Astrophysics Group
Fermilab

The name is in flux...

Context

- SDSS extension
  - 4000 sq-degrees of spectroscopy
- LSST
  - DMT/LSST 8m telescope, giant camera
  - PanSTARRS 4 1m telescopes, big cameras 2007?
- GSMT/CELT
  - 30meter ground telescope, deep spectro
- JWST (aka NGST)
  - 6m space telescope,
  - infrared spectroscopy/imaging
- SNAP ! ... launch in 2015 (!)
- WMAP
  - CMB, flying
- Planck
  - CMB: last word on fluctuations, but on to polarization

Scientific Motivation

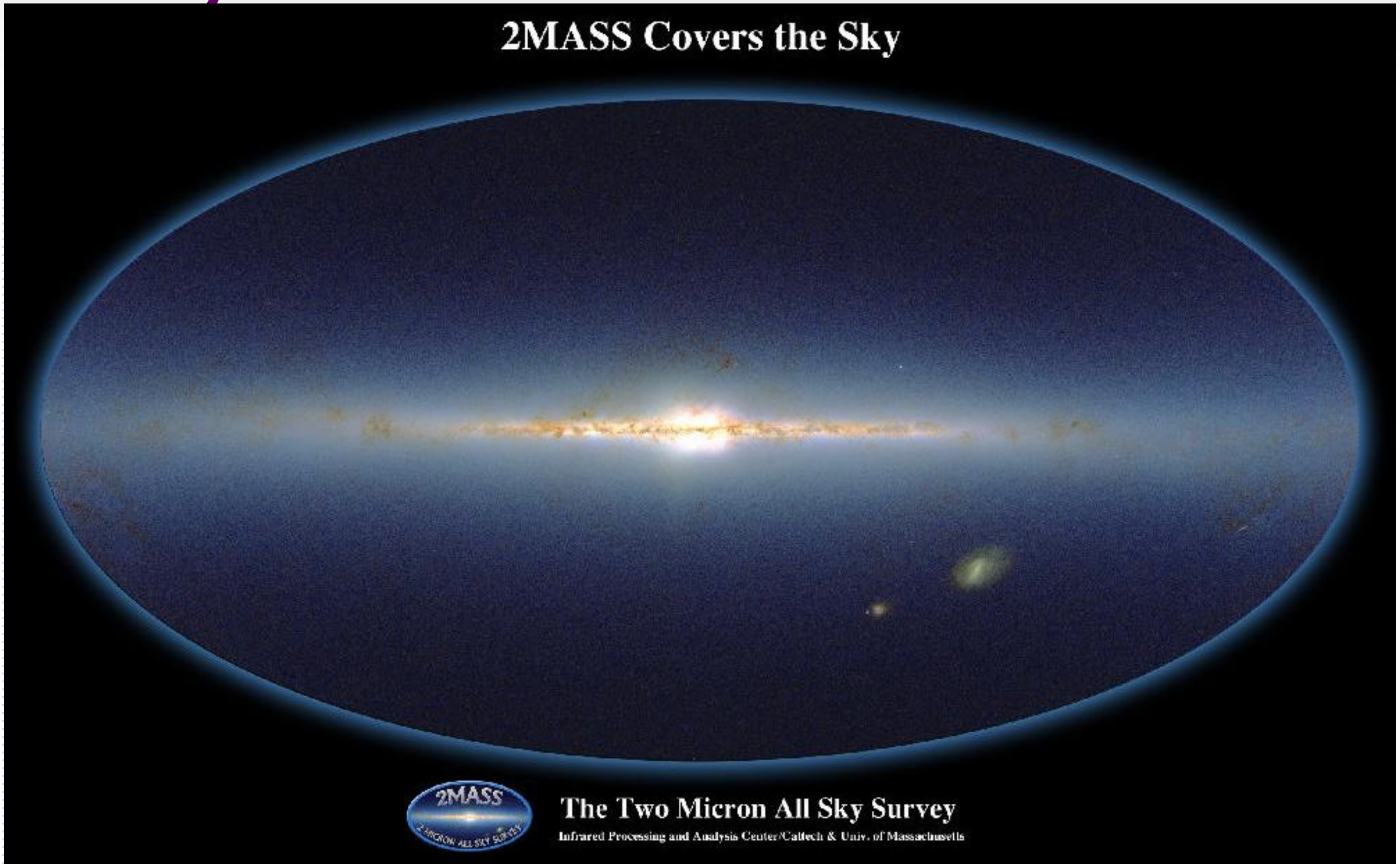
Create the ultimate map of the Universe

- ***The SDSS was a start***

In order to study fundamental physics:

- **What is the dark matter?**
- **What is the dark energy?**
- **What were the conditions during inflation?**

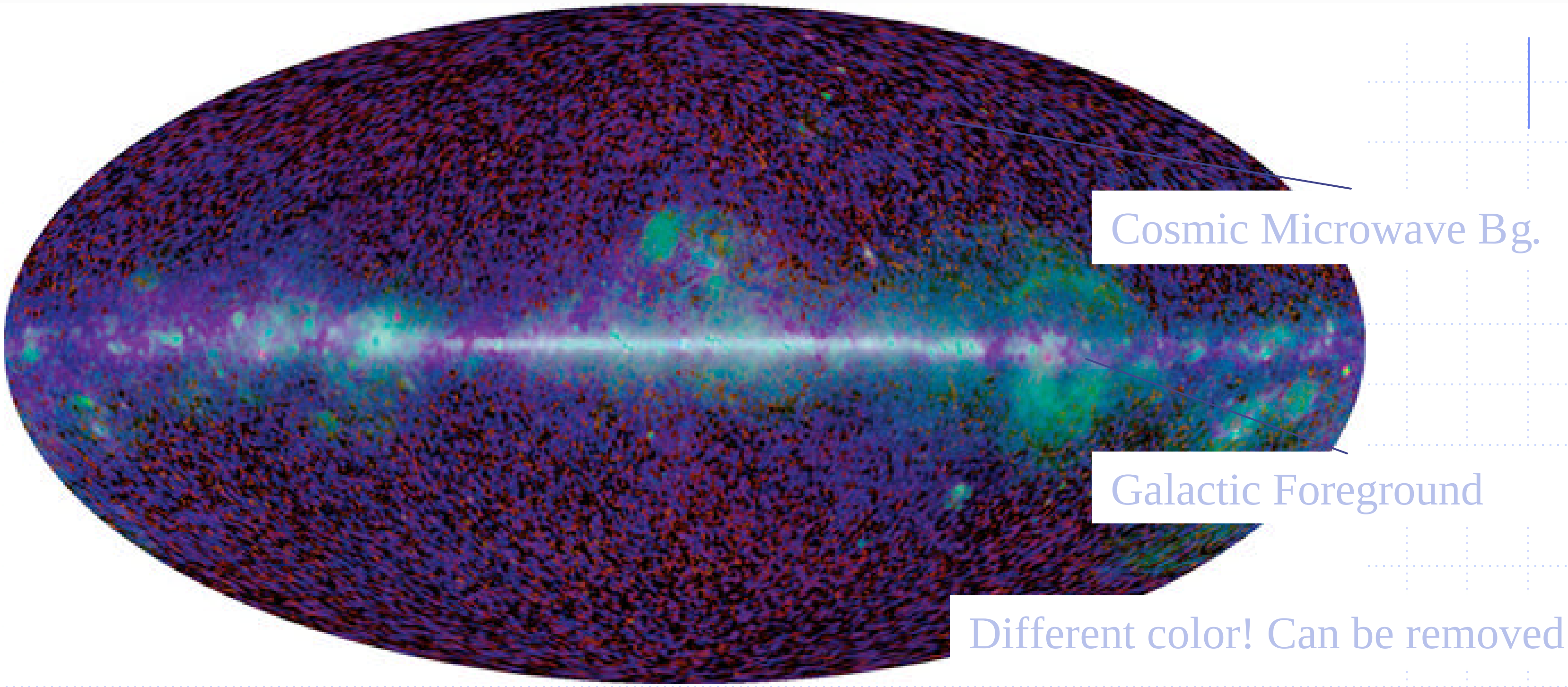
The Two Micron All Sky Survey



Too shallow to do much cosmology

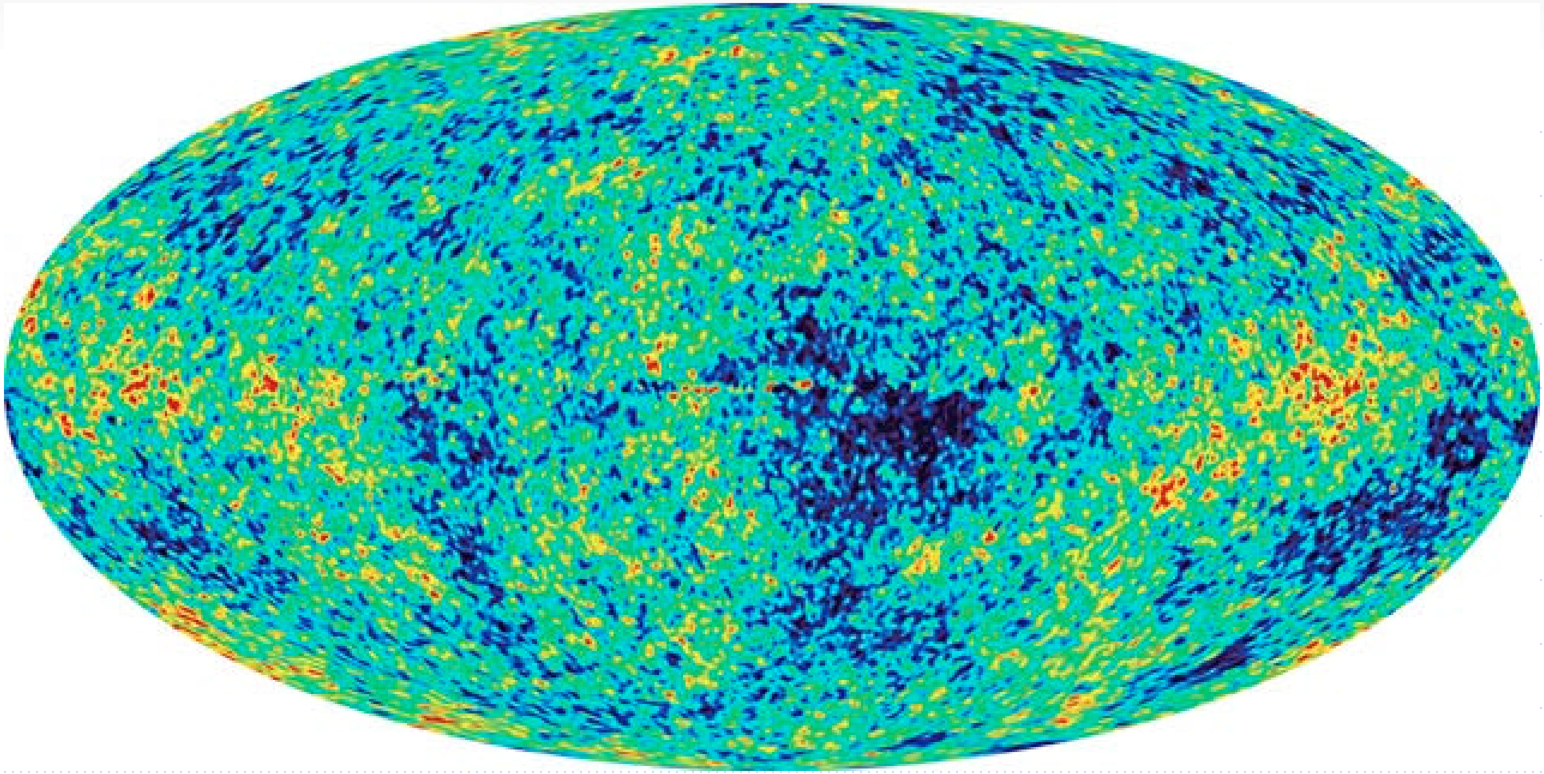
=> Sky coverage must be combined with depth

Wilkonsin Microwave Anisotropy Probe



The CMB is as deep as one can go

The Cosmic Microwave Background

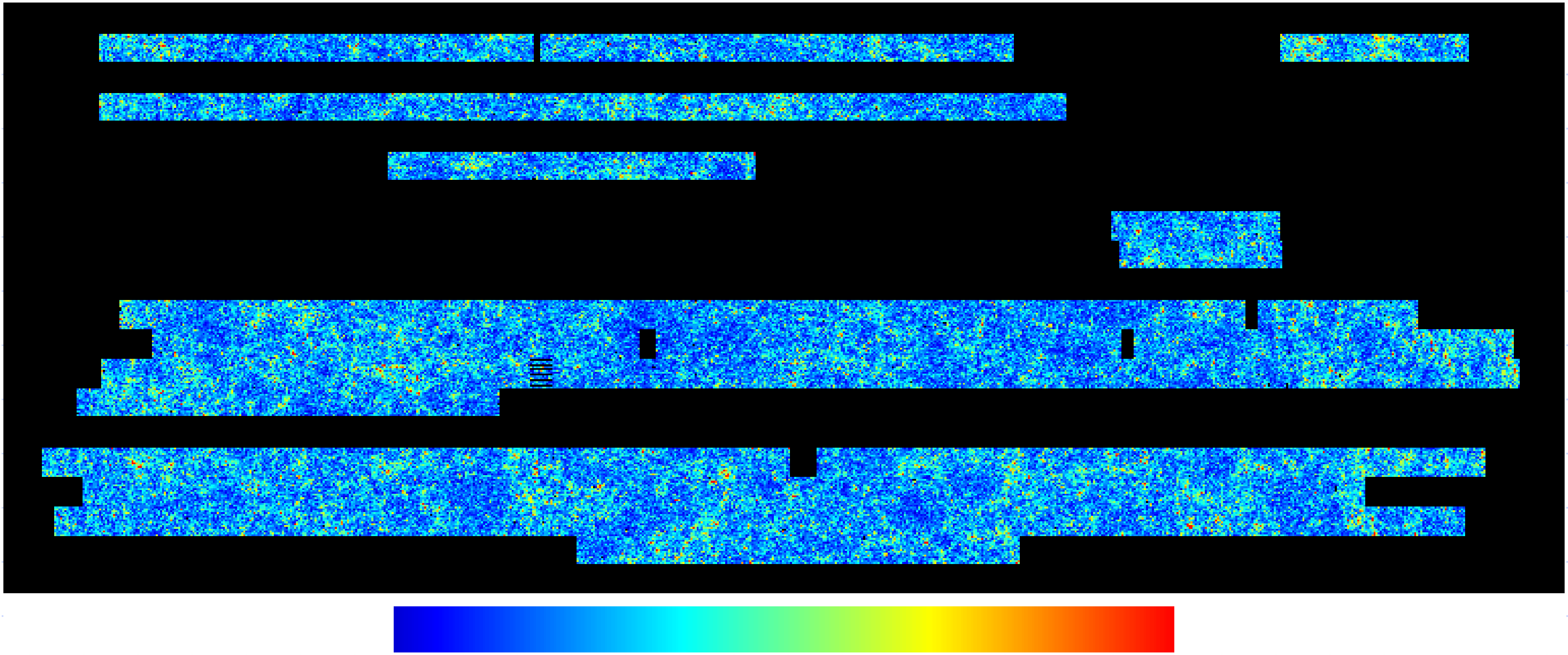


Imprint of density field at time of last scattering

WMAP Team

Properties can be calculated from first principles!

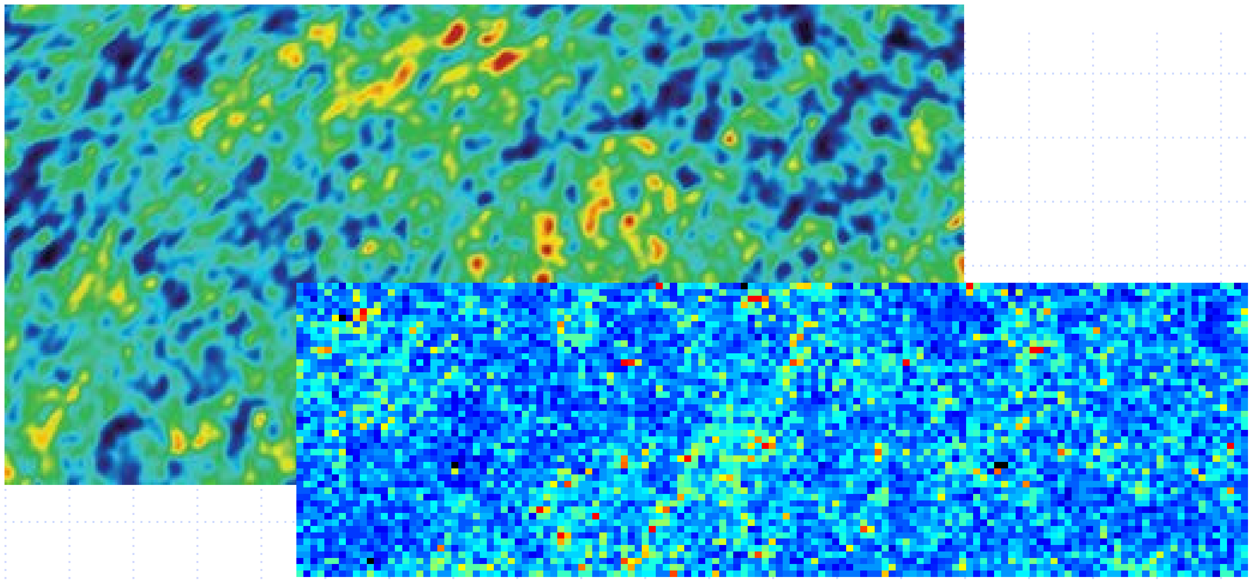
The SDSS DR1 Galaxy Map



Tracer of density field at z ~ 0.3

SDSS LSS Team

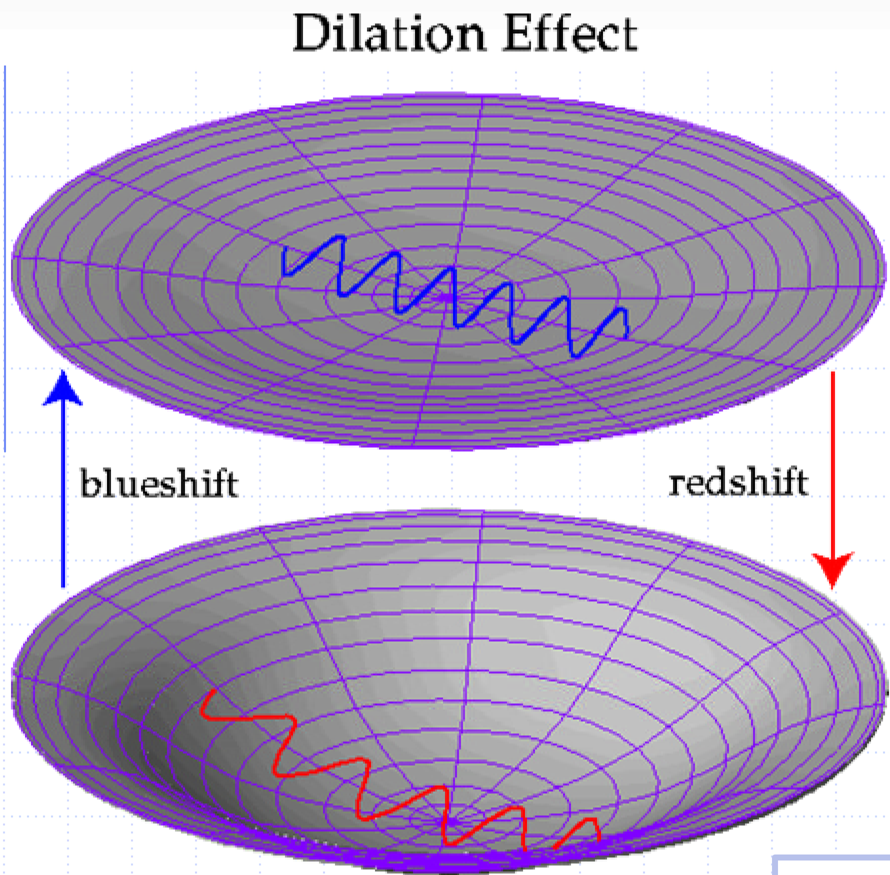
Cross correlate CMB & Galaxies

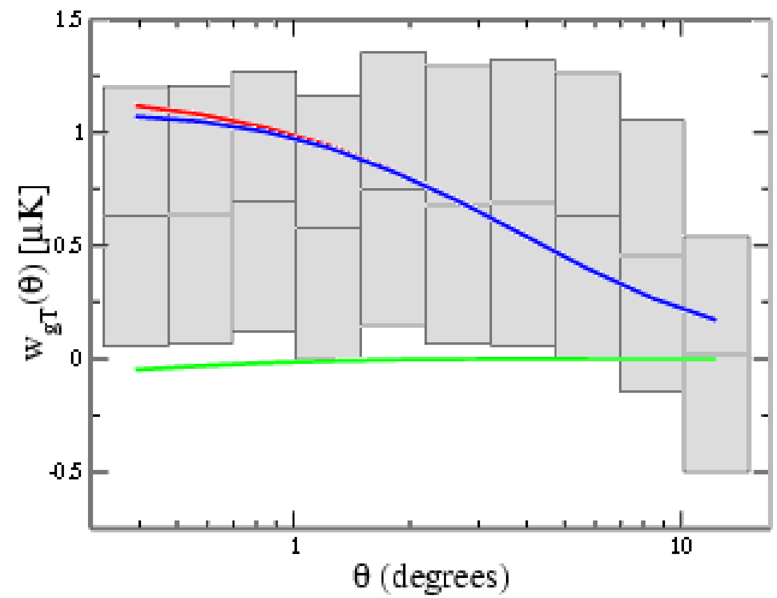


The large scale structure of galaxies and dark matter imprint the CMB photons as they pass to through

=> Cross correlate galaxies with CMB ?!

Integrated Sachs Wolf Effect



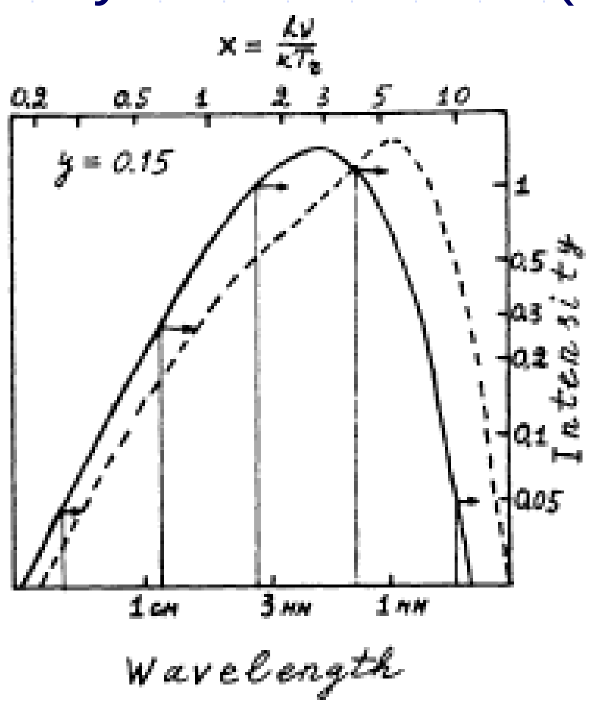


Red is predicted ISW. Green predicted SZ.

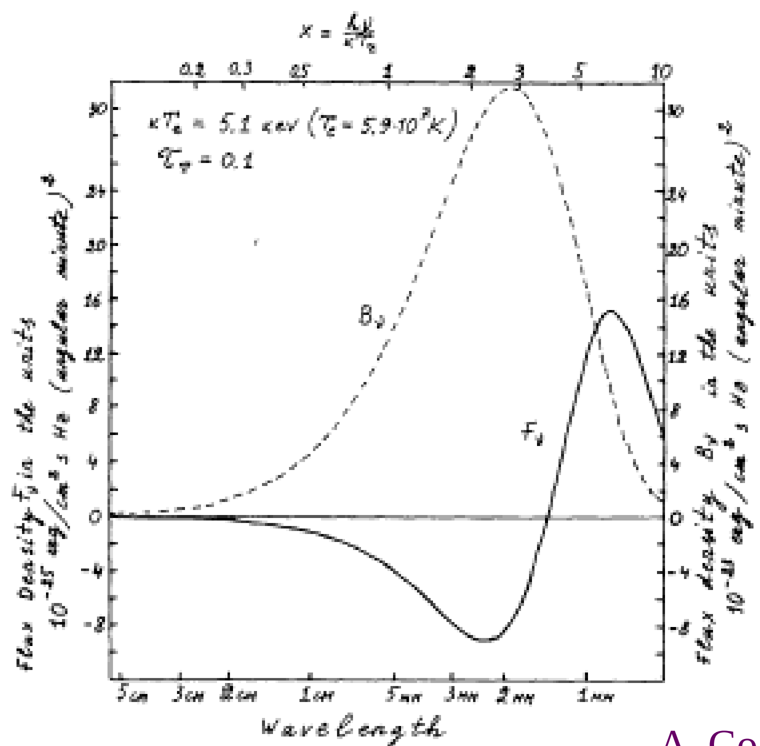
Sunyaev-Zeldovich Effect

⇒ *Scattering moves photons from low frequencies (RJ part of th frequency spectrum) to high frequencies (Wien regime)*

In the language of
Sunyaev-Zel'dovich (1980):



Det Tal



A. Cooray

Frequency shift the CMB blackbody

and the difference (wrt to CMB)

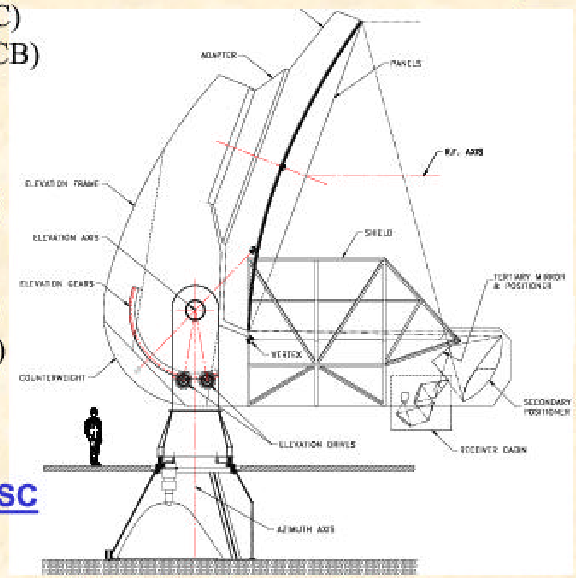
The South Pole Telescope

8m (10m) South Pole Telescope (SPT) and 1000 element bolometer array

PEOPLE

Carlstrom (UC)
Holzapfel (UCB)
Lee (UCB)
Leitch (UC)
Meyer (UC)
Mohr (UIUC)
Padin (UC)
Pryke (UC)
Ruhl (UCSB)
Spieler (UCB)
Stark (CfA)

NSF – OPP
Raytheon PSC
CfCP



Low noise, precision telescope

- 20 um rms surface over 8m
- 1 arcsecond pointing
- 1.25 arcminute at 2 mm
- ‘chop’ entire telescope
- 3 levels of shielding
  - 1 m radius on primary
    8 m precision surface
  - inner moving shields
  - outer fixed shields

SZE and CMB Anisotropy

- at least two bands
  150 & ~250 GHz
- 4000 sq deg SZE survey
- deep CMB anisotropy fields
- deep CMB Polarization fields

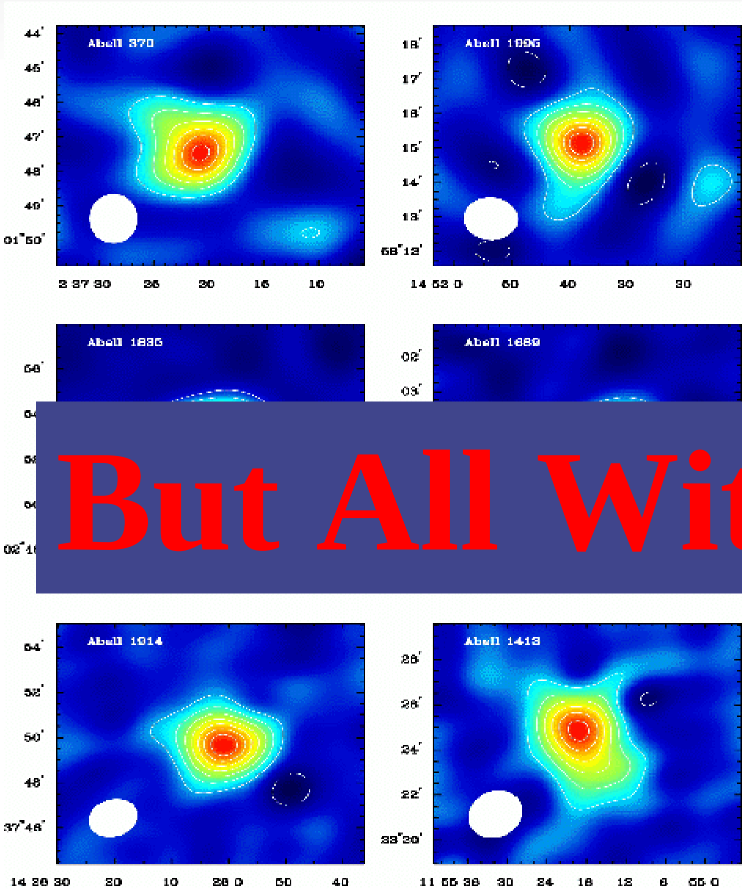
NSF-OPP Funded & scheduled for Nov 2006 deployment

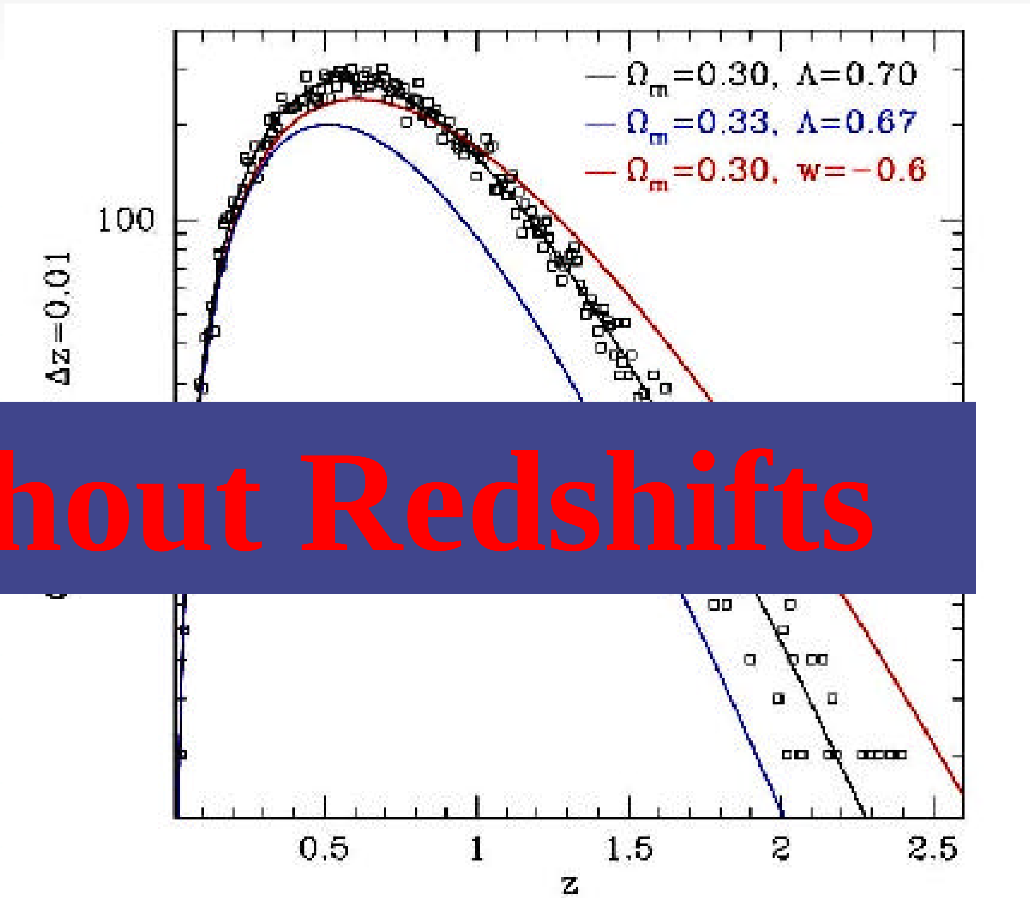
D_z

J. Carlstrom

SPT 4000 sq degree Survey

Could be done in one austral winter



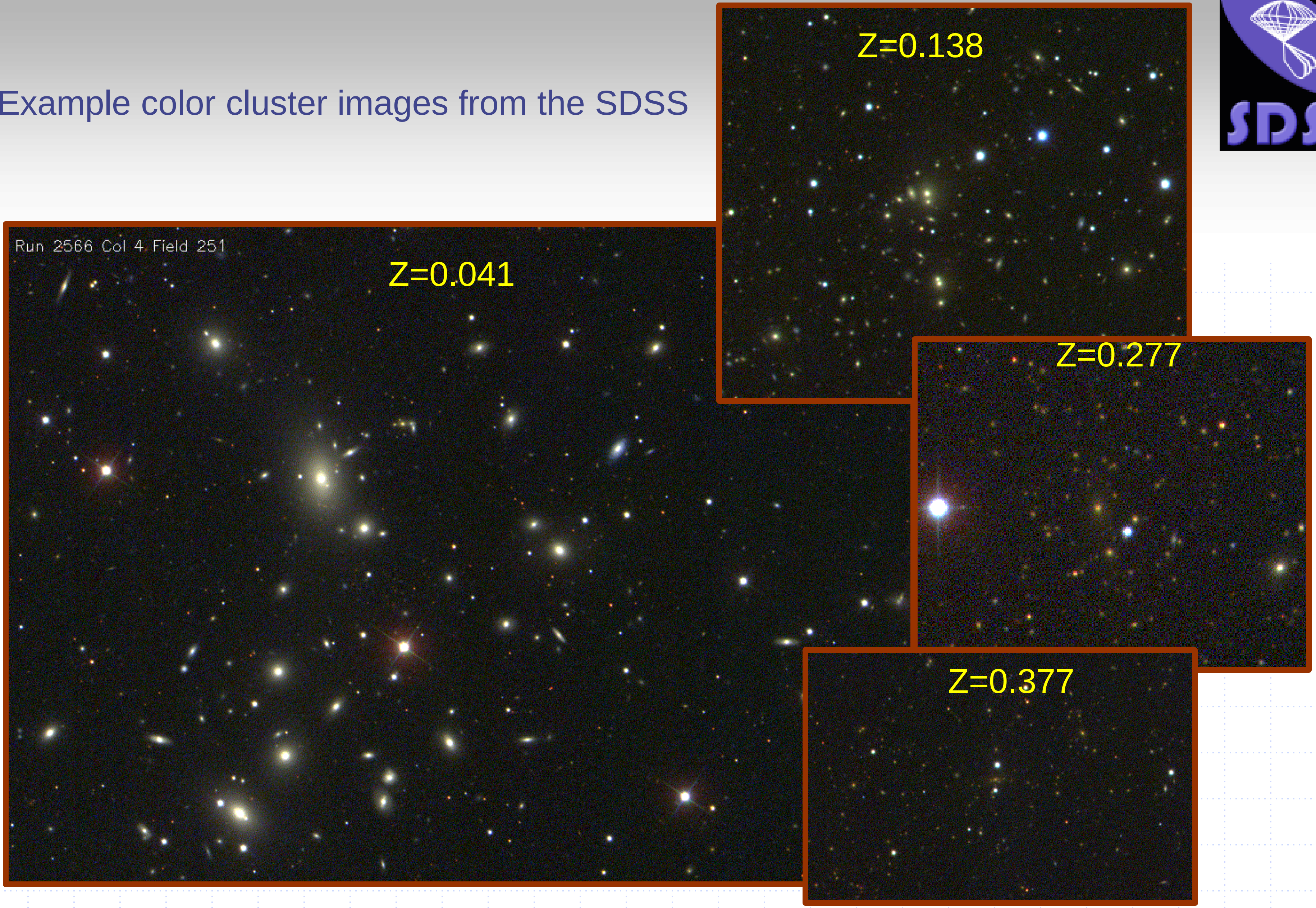


But All Without Redshifts

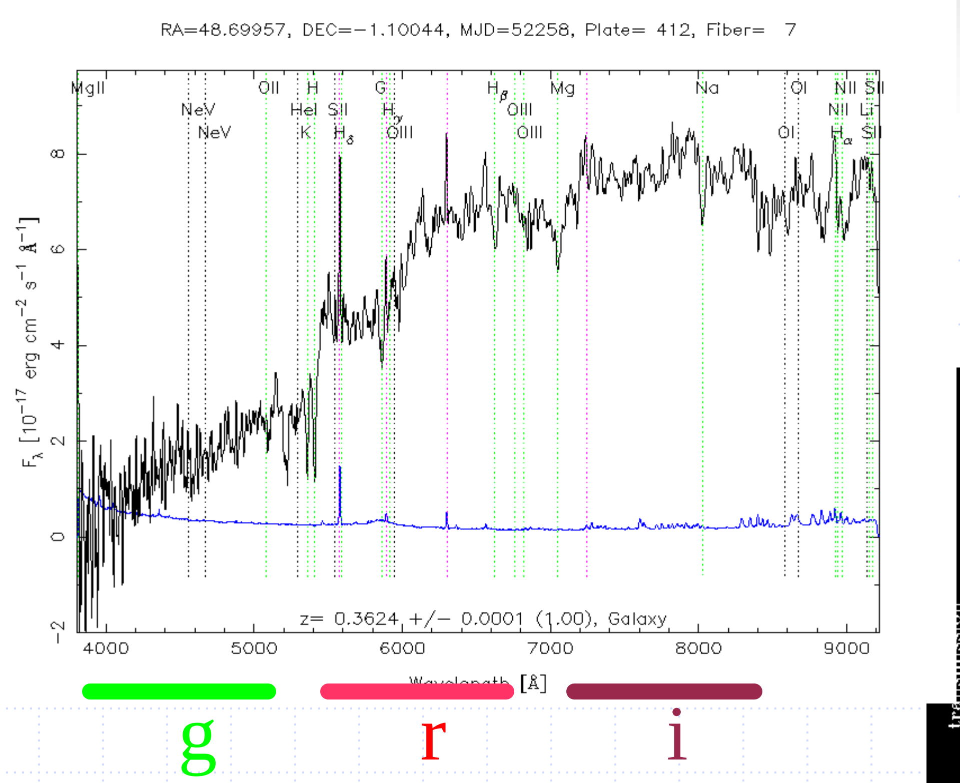
SZ observations of clusters

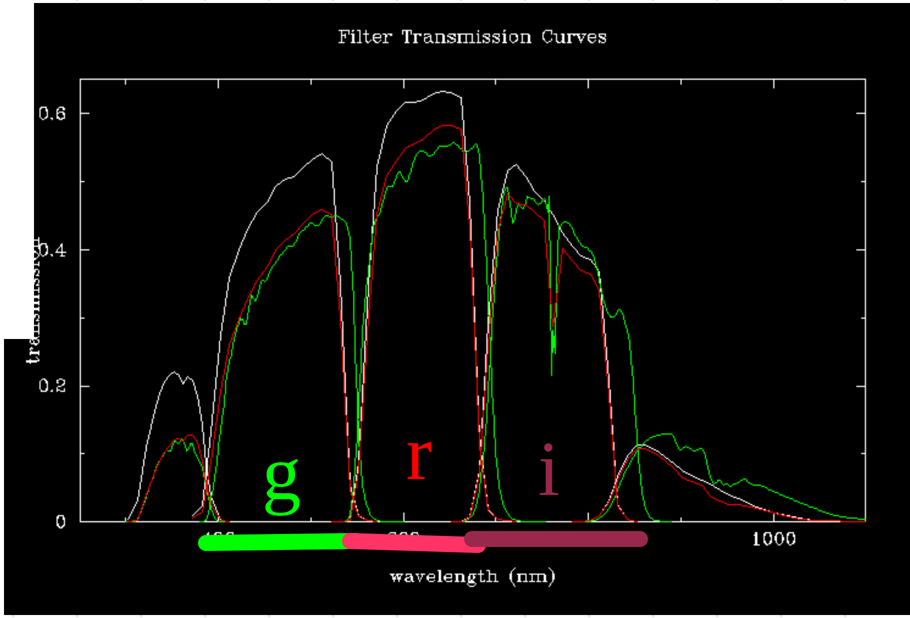
dN/dz for 4000 sq-degree
20,000 clusters, 80% z <= 1

Example color cluster images from the SDSS



Elliptical Galaxy Spectrum



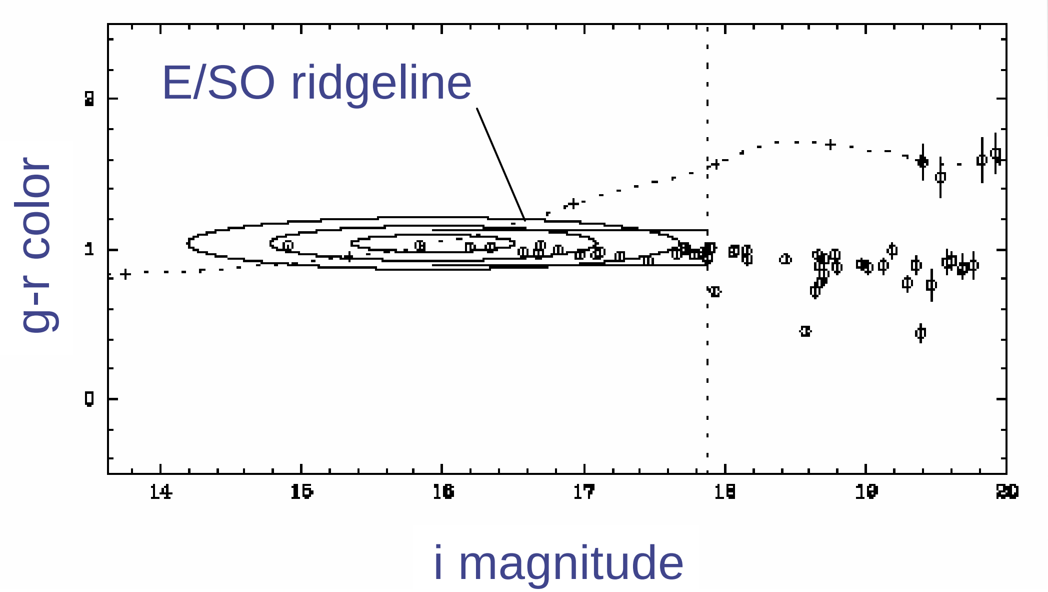


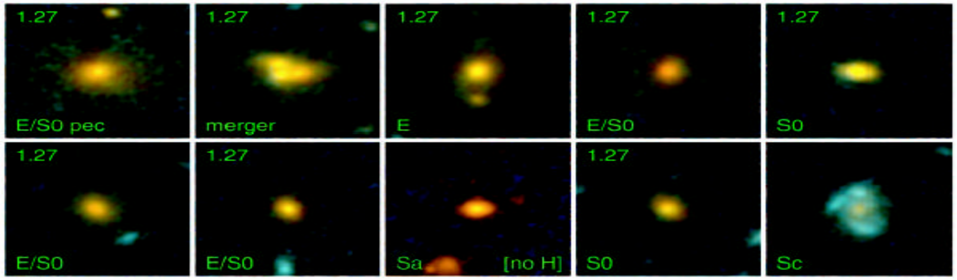
D_z Project

SiDet Talk, Oct 27 2003

Finding red sequence clusters

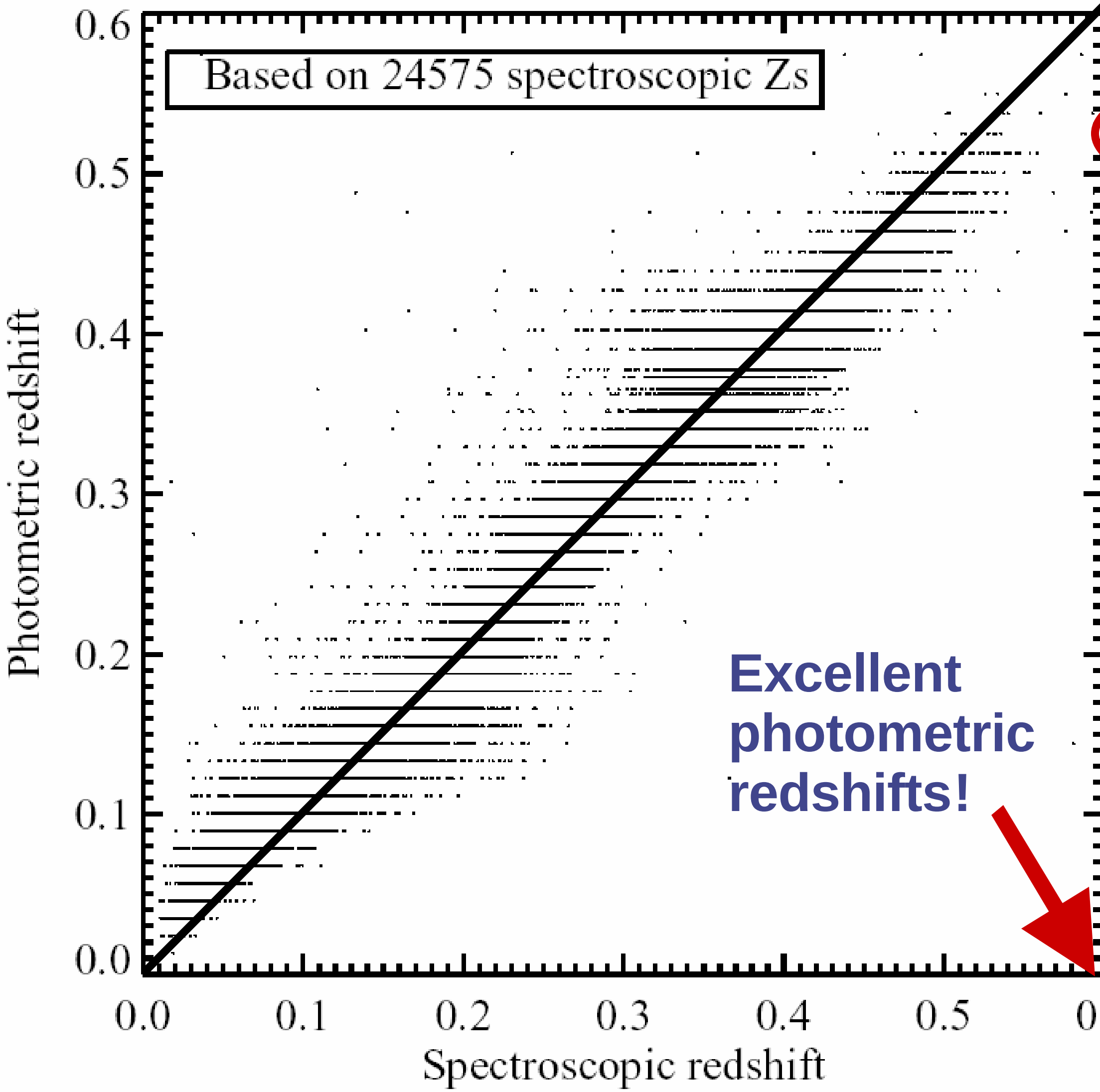
- Clustering in position-color space essentially eliminates contamination by projection
- Gladders & Yee (2000), Goto et al. (2001), Annis et al. (2003)
- E/SO ridgeline provides extremely accurate ($\Delta z \approx 0.01$) photometric redshift
- Red sequence in place throughout SDSS volume and beyond, to z>1….



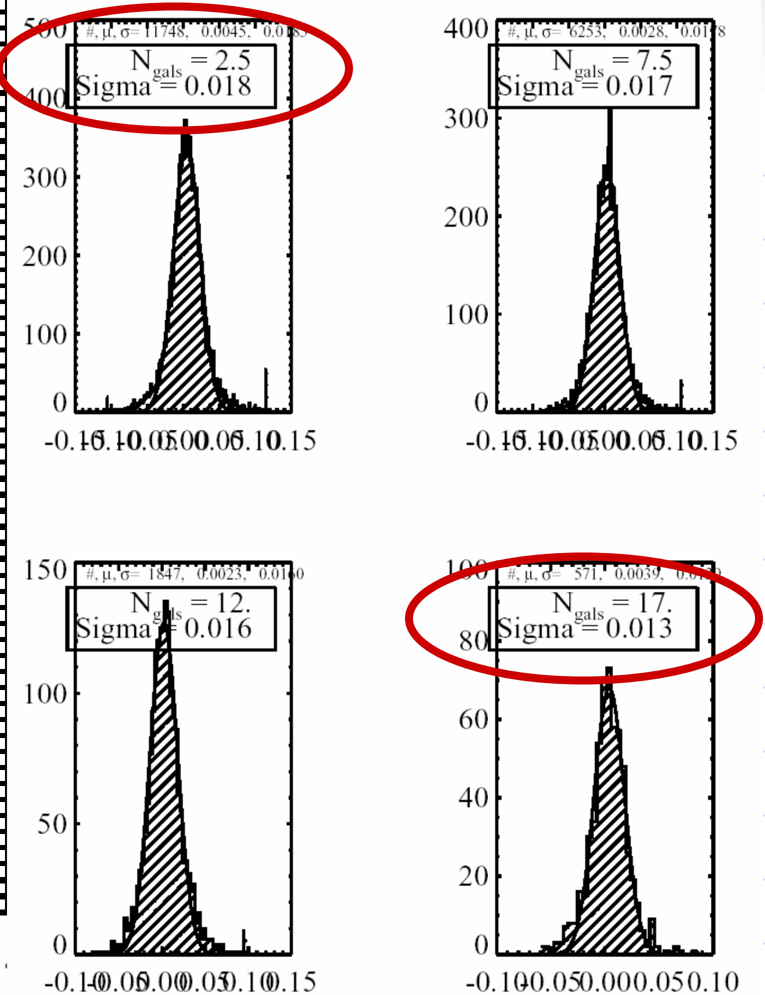


Red sequence galaxies at z=1.27 (van Dokkum et al, 2000)

The maxBCG sample: redshift



Excellent photometric redshifts!



CMB Optical Followup:

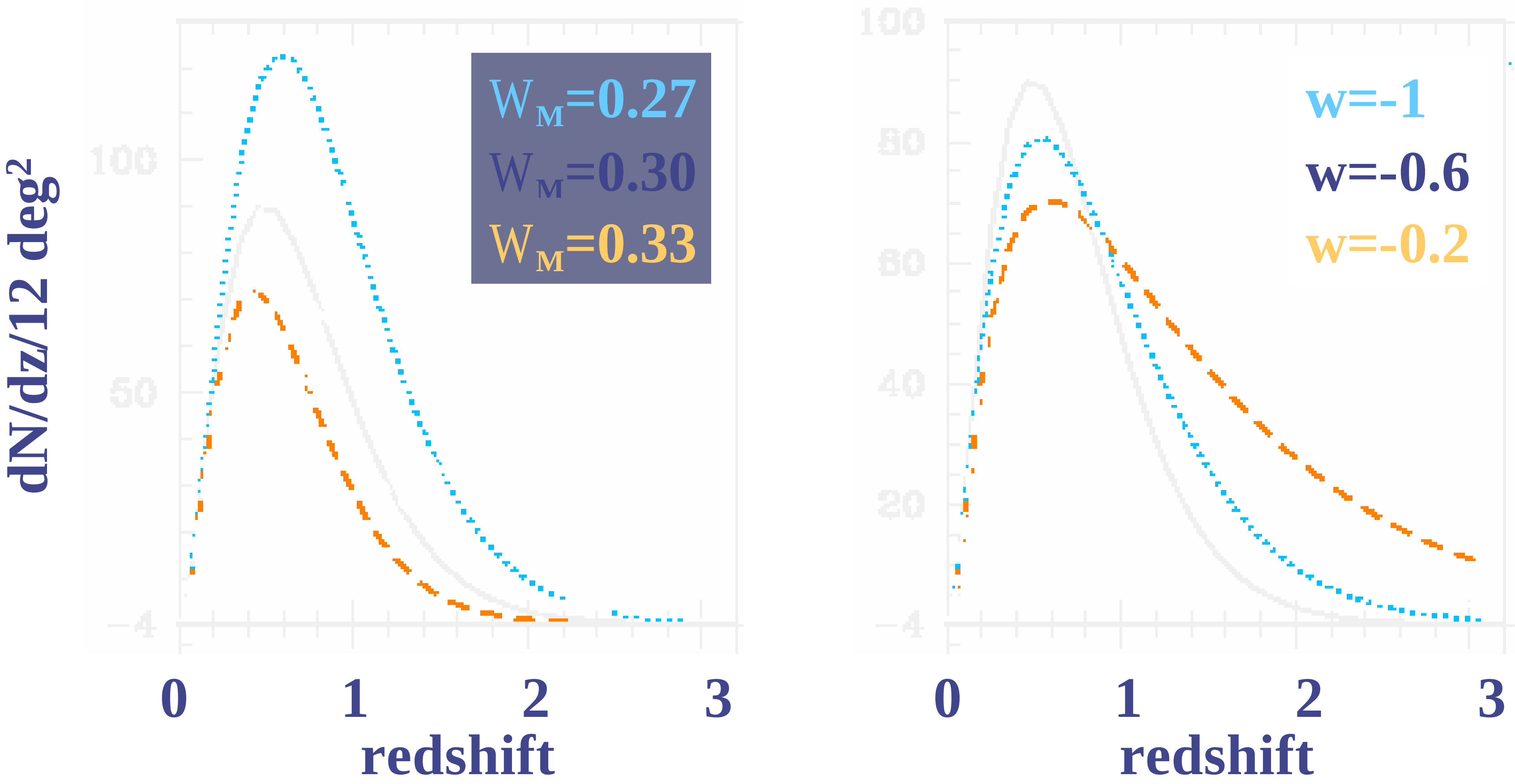
- One follows up by a 4000 square degree imaging survey, in 4 bandpasses, to i~24. This allows:

- Photometric redshifts for ~25,000 SZ clusters
- Optically selected sample of clusters
  - redshift and mass estimates
- Weak lensing mass estimates of these clusters
- Weak lensing cosmic shear measurements
  - with photo-z tomography
- Galaxy clustering on large scales to z ~ 1
- Galaxy-galaxy lensing

… and much more.

Sensitivity to Ω_M ,w in SZ Survey

Haiman, Mohr &



overall scaling and σ_8 change

volume (low-z) + growth (high-z)

An advantage unique to clusters?

- **A cluster sample can deliver <u>many</u> observables**

SZE decrement	X-ray flux
Angular size	Number of galaxies
Spatial distribution (2d, 3d)	Lensing signatures

- **We can construct <u>several</u> cosmology tests**

dN/dz – abundance evolution (including mass function dN/dM)	**Best?**
P(k) – spatial power spectrum (including Alcock-Paczynski)	**better**
Scaling relations – between SZ/X-rays/sizes (including d_A measurement)	**good**

Simultaneous determination of cosmological and cluster structural parameters (with their evolution)

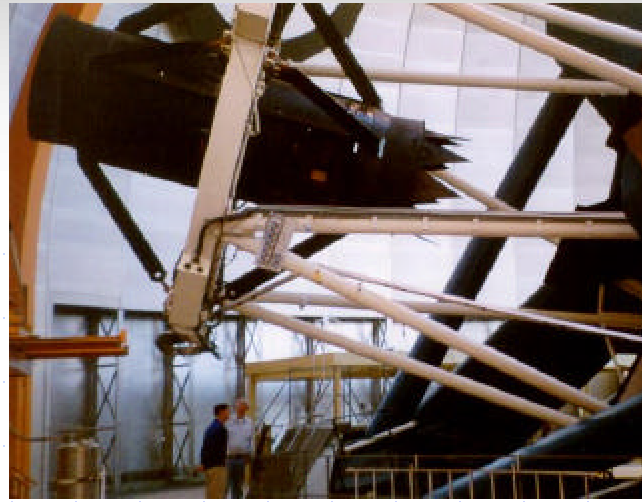
CMB/Galaxy/Weak Lensing Science

- Combine WL and SZ on cluster catalog
- Cross correlation of WL and secondary CMB
- Joint Analysis of CMB and WL power spectra
- Cross correlation of CMB and cluster catalog: SZ
- Cross correlation of CMB and galaxy catalog: ISW
- CMB polarization of CMB towards cluster catalog
- Cross correlate CMB polarization with galaxy catalog
- Power spectra of cluster catalog with photo-z
  - Redshifting Rings of Power (!)
- The Cosmology with Sunyaev-Zeldovich Cluster Surveys Conference

- Cooray 2003 (astroph/0305515)
- Takada and Sugiyama 2001 (astroph/0110313)
- Ishak et al 2003 (astroph/03084461)
- Komatsu et al 2000 (astroph/0012196)
- Scranton et al 2003 (astroph/0307335)
- Cooray and Baumann 2002 (astroph/0211095)
- Benabed et al 2000 (astroph/0003376)
- Hu and Haiman 2003 (astroph/0306053)
- http://bubba.ucdavis.edu/~sz03

A rich field with much interesting physics

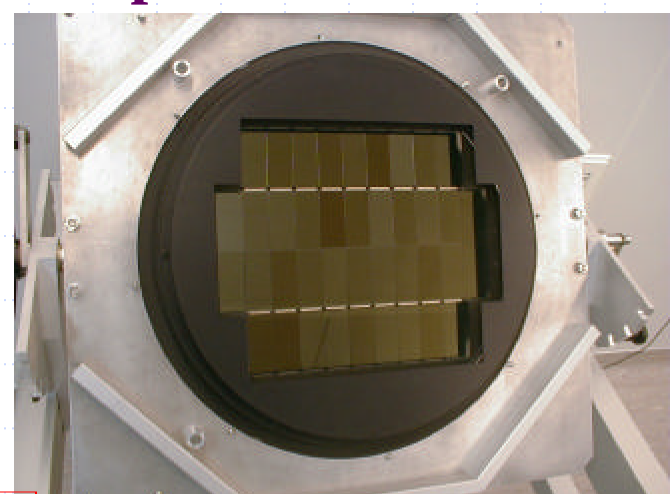
A Wide Field Imager on the CTIO Blanco 4m



- Collecting area:10 m^2
- Prime focus:
  - f/2.87
  - 15 micron pixels => 0.267"/pixel
  - Field of view (diameter):
    - Current: 0.8 degree
    - Need: 2 degree

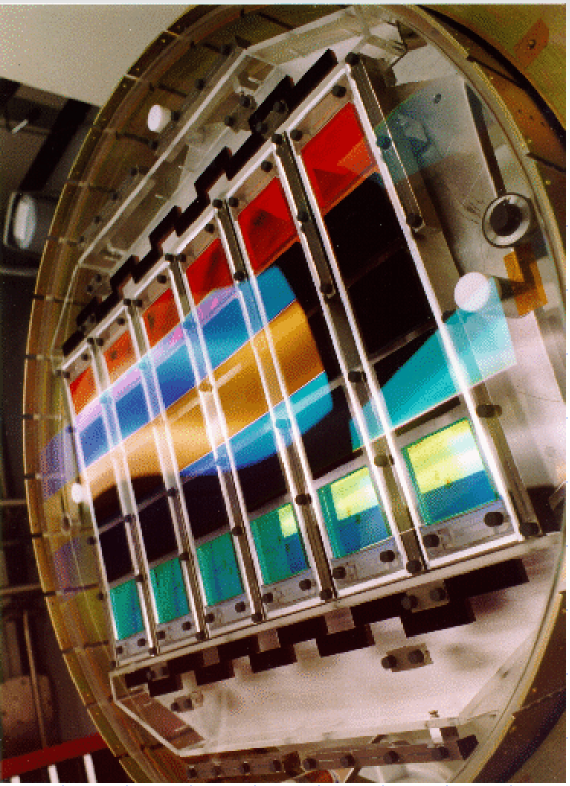
A project in which Fermilab could take a leadership role

- Need to build a 20k x 20k pixel Camera
  - 400 Megapixel
  - Big. State of the art last January: Megacam at 16k x 16k
  - 2007-2008?



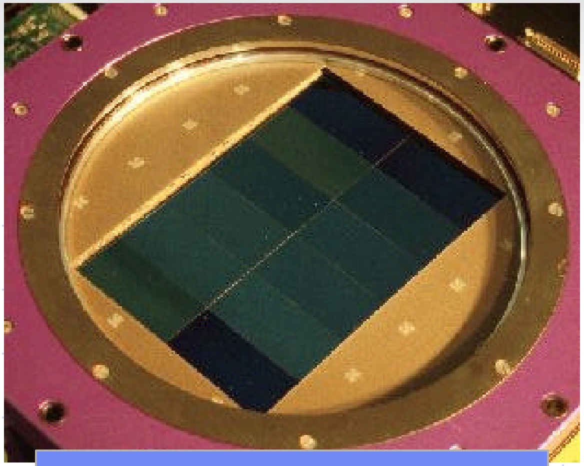
A four filter survey to i=24 over 4000 sq-degrees

Large format cameras



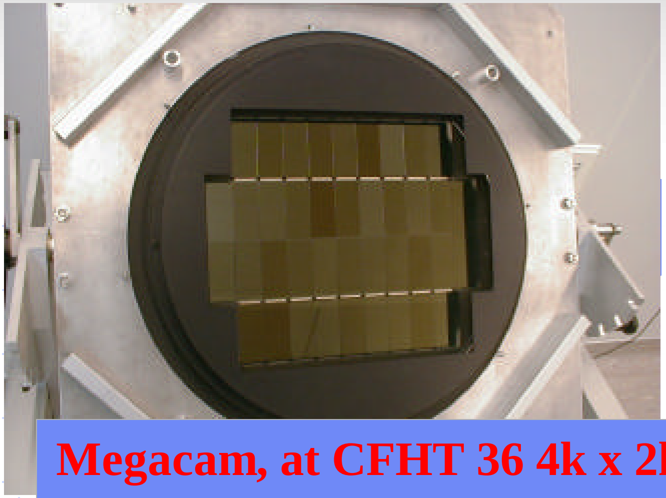
SDSS 30 2k x 2k

120 Megapix 1998



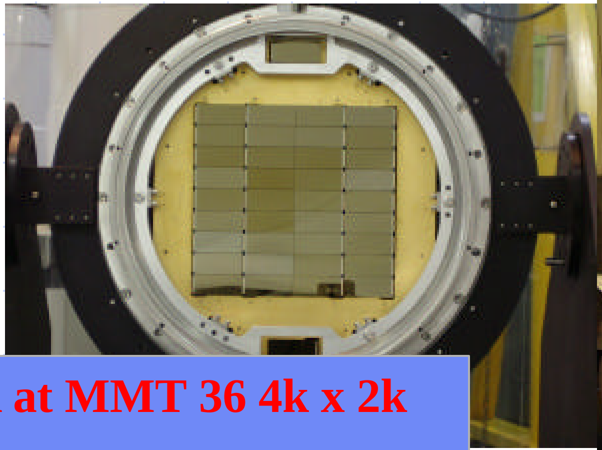
CFH12k 12 4k x 2k

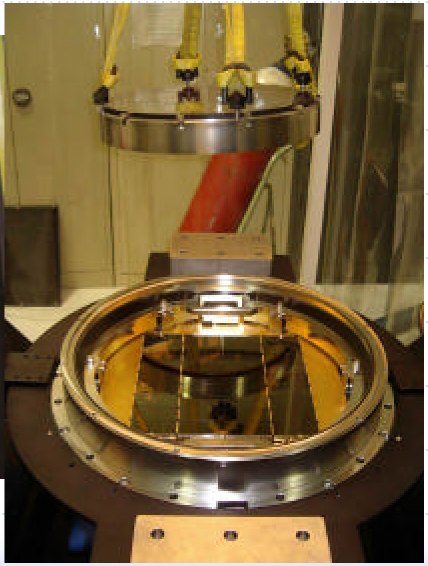
100 Megapix 2000



Megacam, at CFHT 36 4k x 2k

300 Megapix 2003

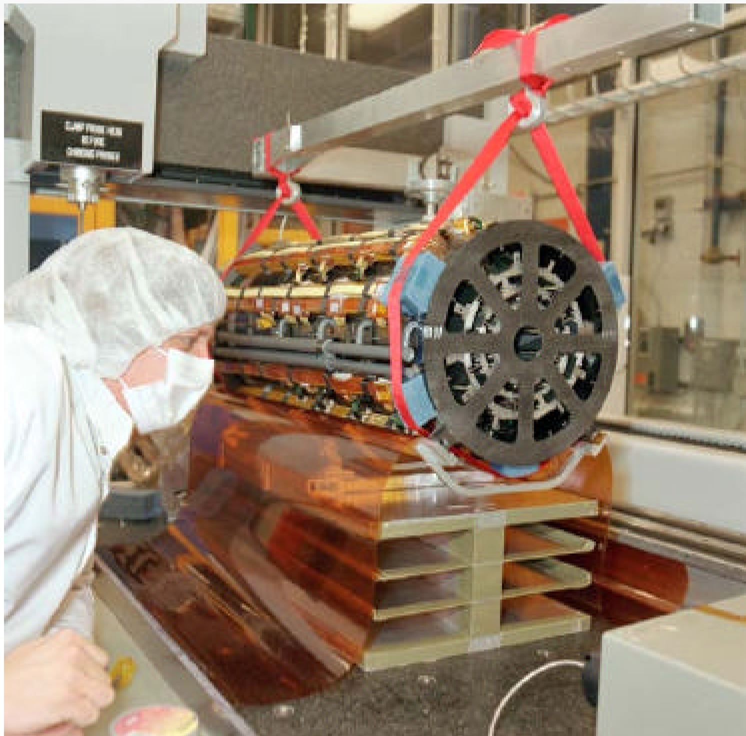




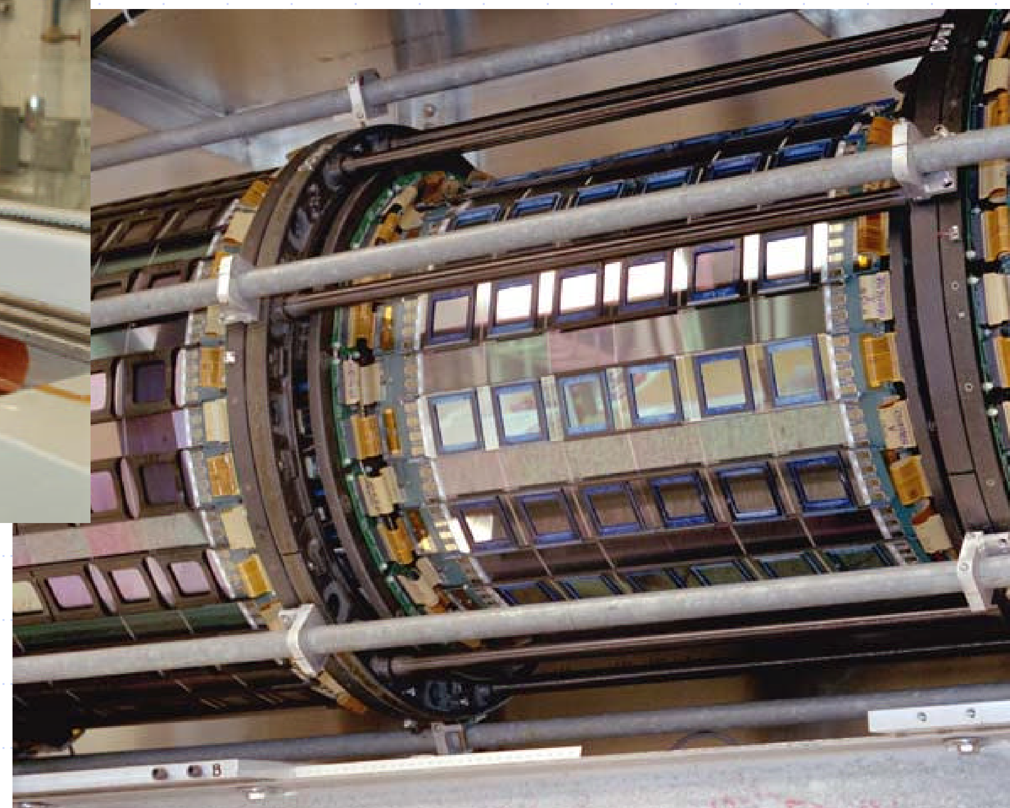
Megacam at MMT 36 4k x 2k

300 Megapix 2003

We can do that...



Ok, the folks of SiDet know how to do that...



Elements of a Survey

Science case! for proposals

- Wide field corrector
- Camera
  - CCDs/detectors
  - Electronics
    - Readout
    - Control
  - Mechanical
  - Vacuum systems
  - Cooling systems
- Data acquisition system
  - Hardware
  - software
- Survey observation strategy
- Standard star strategy
- Science Software
  - Calibration pipeline
  - Coadd pipeline
  - Galaxy measurement pipeline
  - Cluster finding pipeline
- Data production
- Data distribution
-
- Science Analysis

MegaPrime/MegaCam

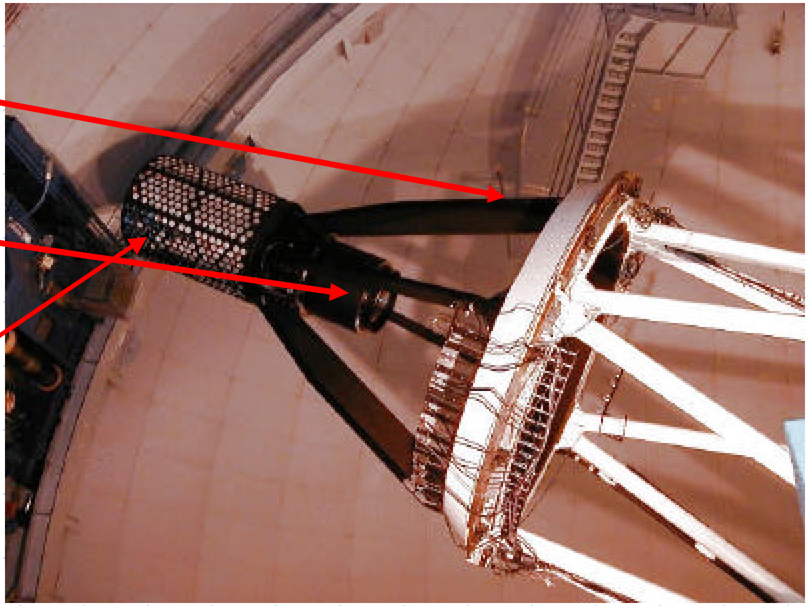
- The MegaPrime project and MegaCam camera is a very good prototype for us.
- On 3.6m CFHT telescope at prime focus
- MegaCam built by DAPNIA
- Corrector built by HAO
- Project run by CFHT.

We'll walk through images from that project.

What would building deCamera really mean?

A system including silicon

- Prime focus cage
- Corrector
- Focus assembly
- Shutter
- Filter Wheel
- Camera



The Upper End

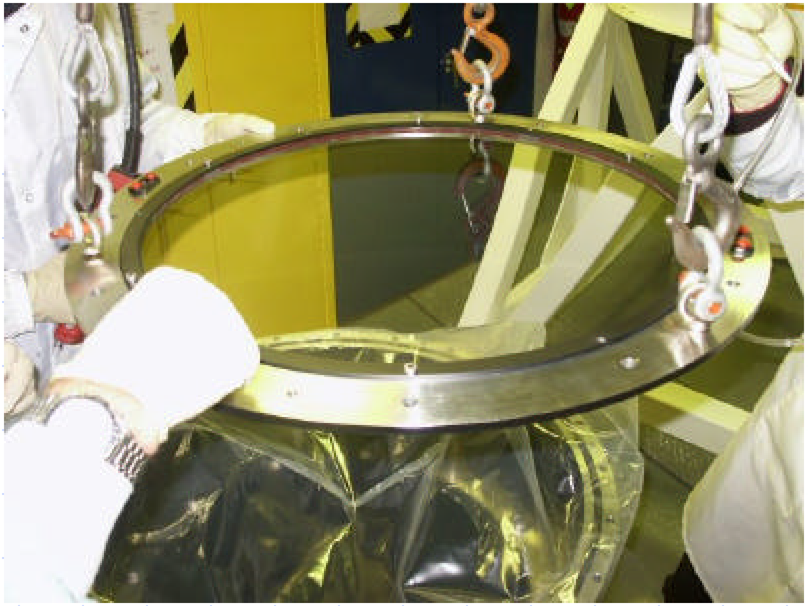
- The prime focus cage is the backbone to which the other components bolt.

Assembling the Corrector

- L1 into place

Assembling the Corrector

- L3 inspection

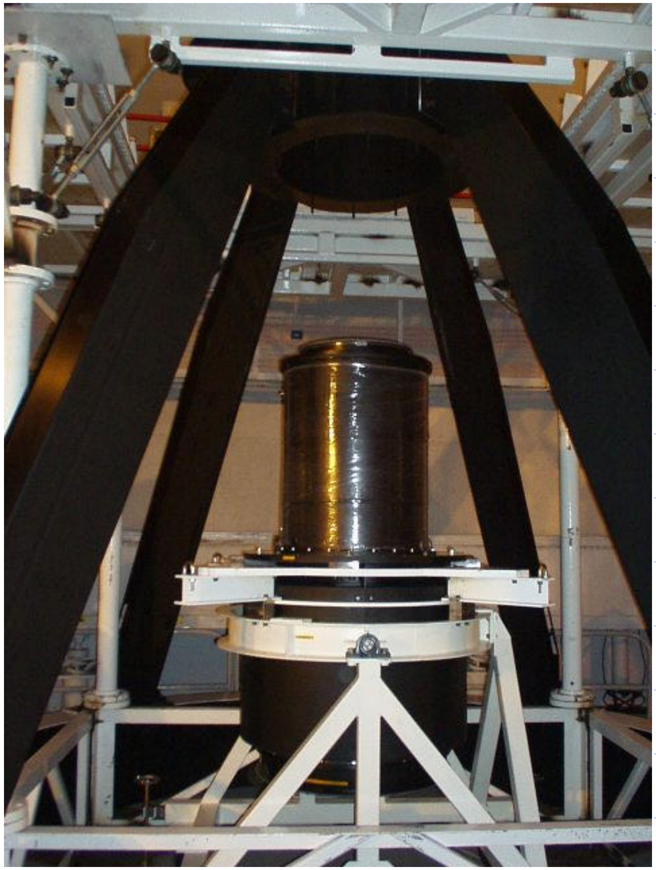


Assembling the Corrector

- 3 or 4 lenses
- ~ 1 meter diameter
- Stack ~ 2 meters high

Mate Corrector to Upper End

- Hangs upside down
- Will tilt to >60 degrees



Focus Stage Assembly

- One must move the corrector and focal plane up and down.
- Perhaps translation as well

- Up/down is focus
- Translation is collimation

Shutter Assembly

- Shutter needs to open/close on ~1 second scales
- Spinning half disk is one solution.

Filter Wheel Jukebox with Base Plate

- Filters have to be placed in the beam.
- 4 filters for the survey, perhaps others for general use.

Mechanical Base Plate during Deformation Tests

- Did I mention tilting to 60 degrees?

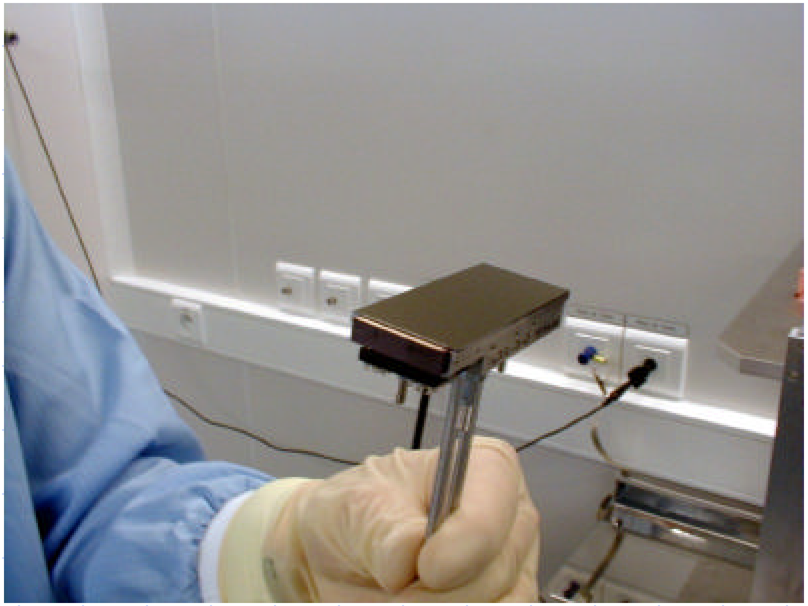
CCD test bench

- The CCDs one acquires will have to be tested during the acceptence process.

- Uniform light source
- Small DA
- Vacuum/cryo

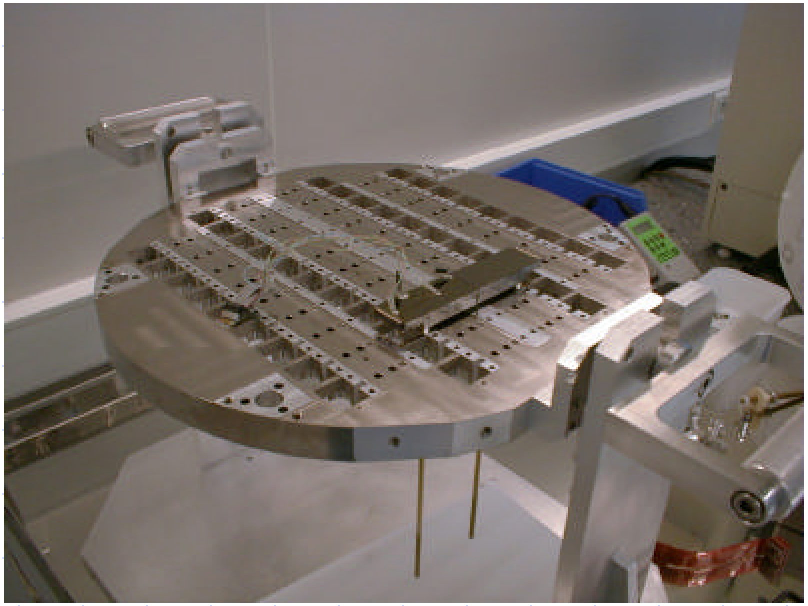
Handling CCDs

- ... coals to Newcastle...



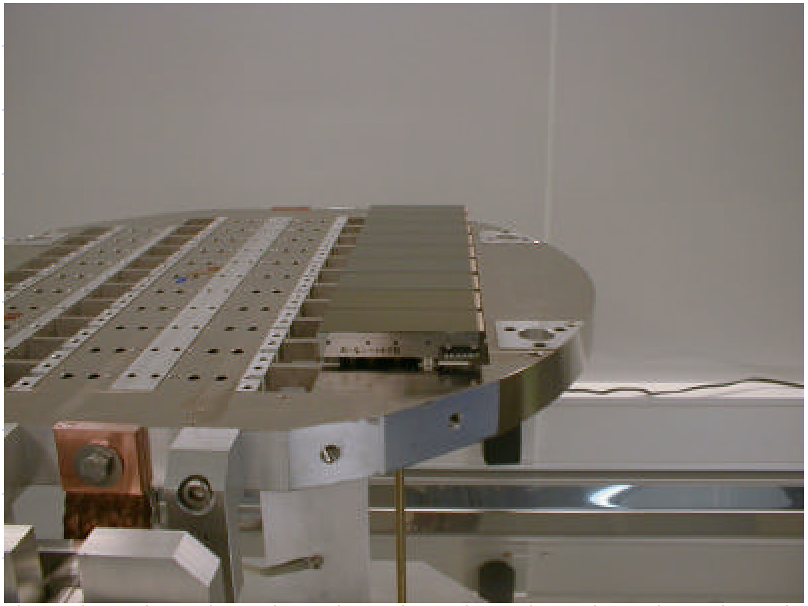
Cold Plate

- This is the base plate, and is cooled to ~180 K.



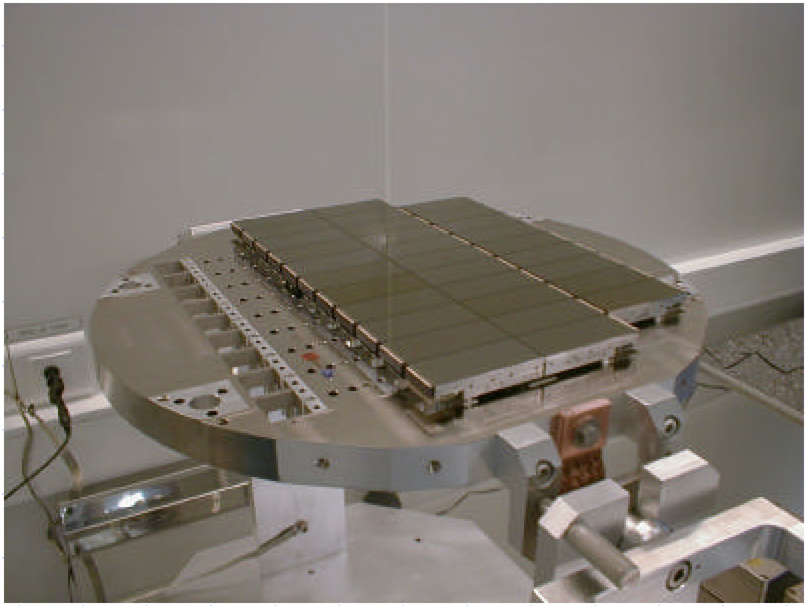
First row of ccds

- Pretty...



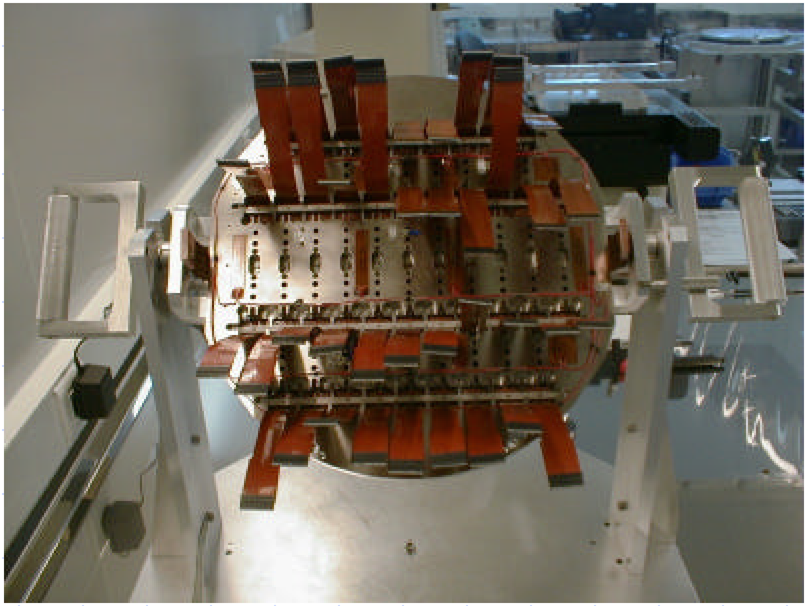
Third row

- Better…



Flex cables

- These connect to the dewar, where special purpose connectors pass through the dewar walls to the electronics.

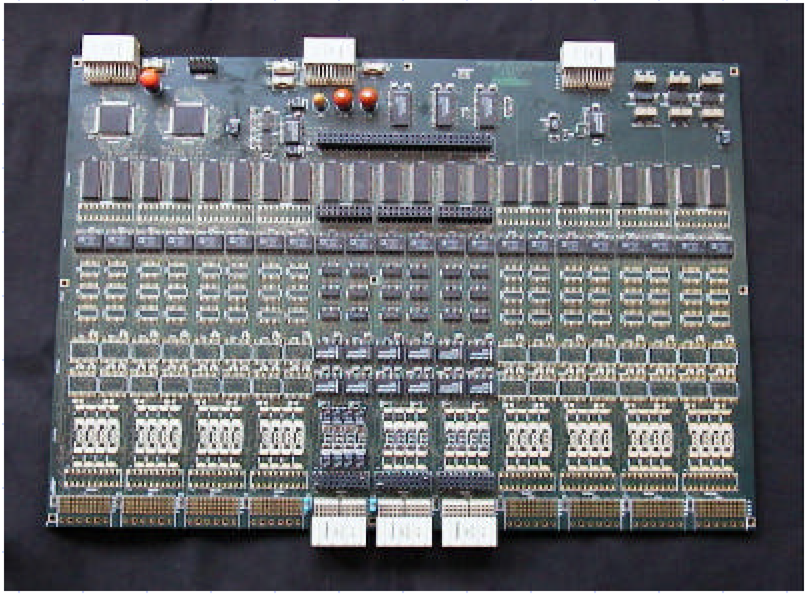


CCD Mosaic

- Now that is nice.

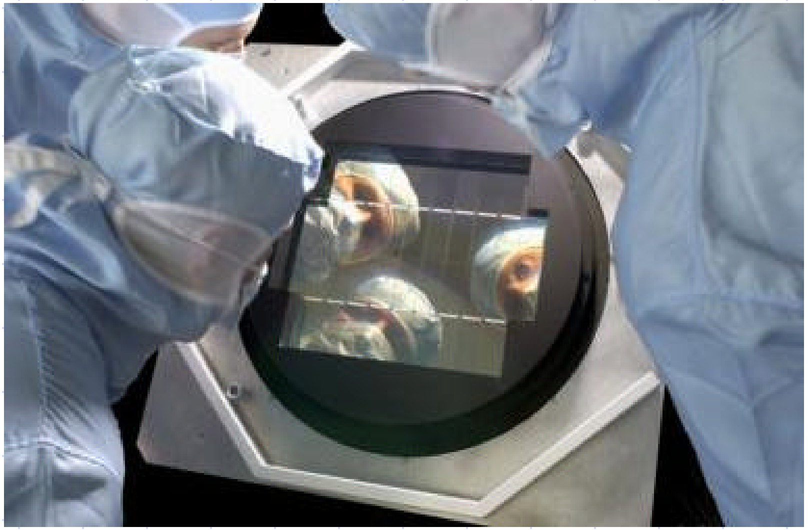
Readout electronics

- There are on order of 80 channels in Megaprime, reading at ~ 1 MHZ.



Mosaic through dewar window

- The mounting plate.

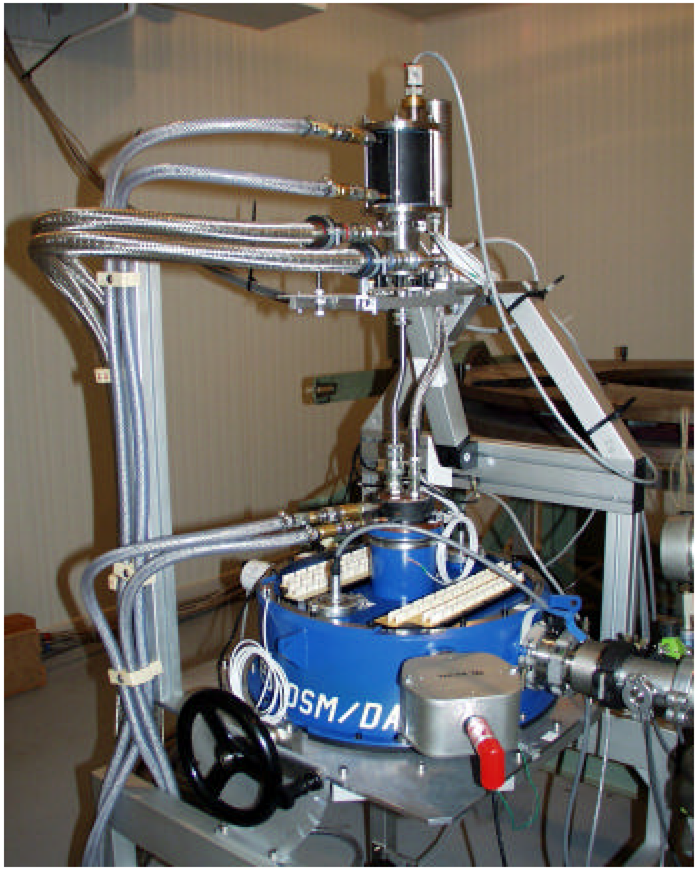


Cryostat during vacuum test

- There is a cyrovessel. LN2 temperatures, and month long hold times.

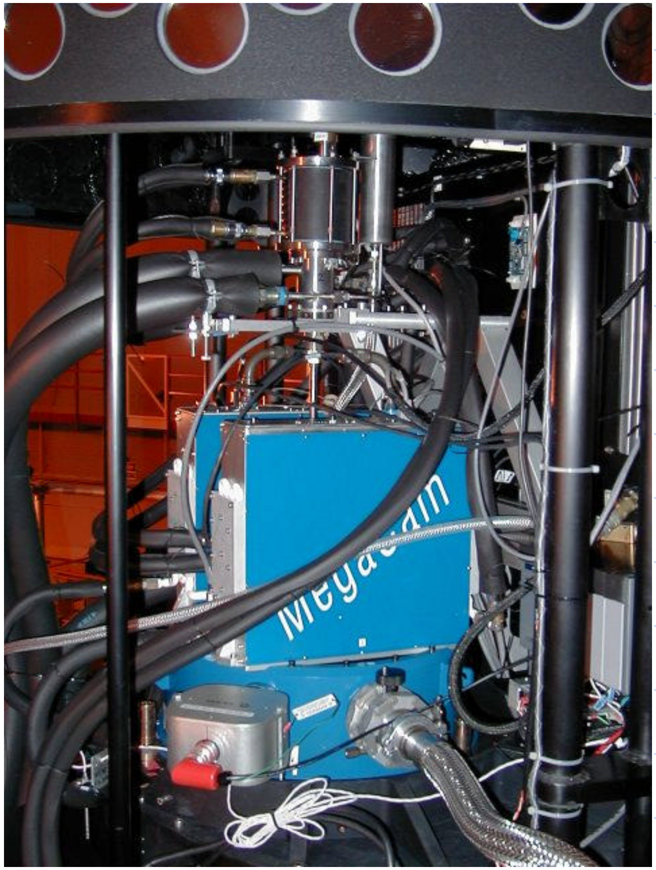
Camera ready to be cooled down

- Vacuum pumps?
- Actually, I think this is the pulse refrigerator.



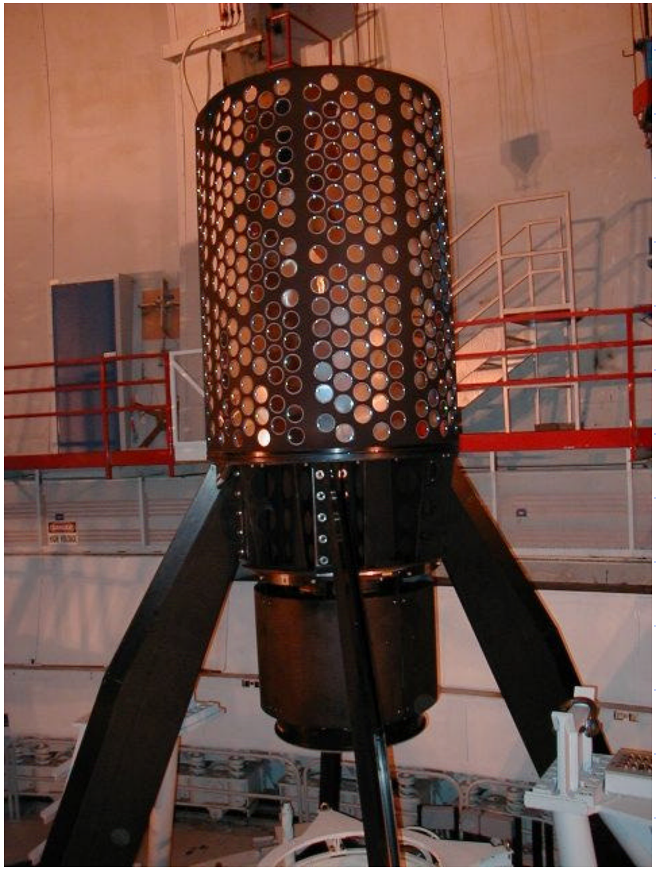
MegaCam

- The camera bolted to the sheath.



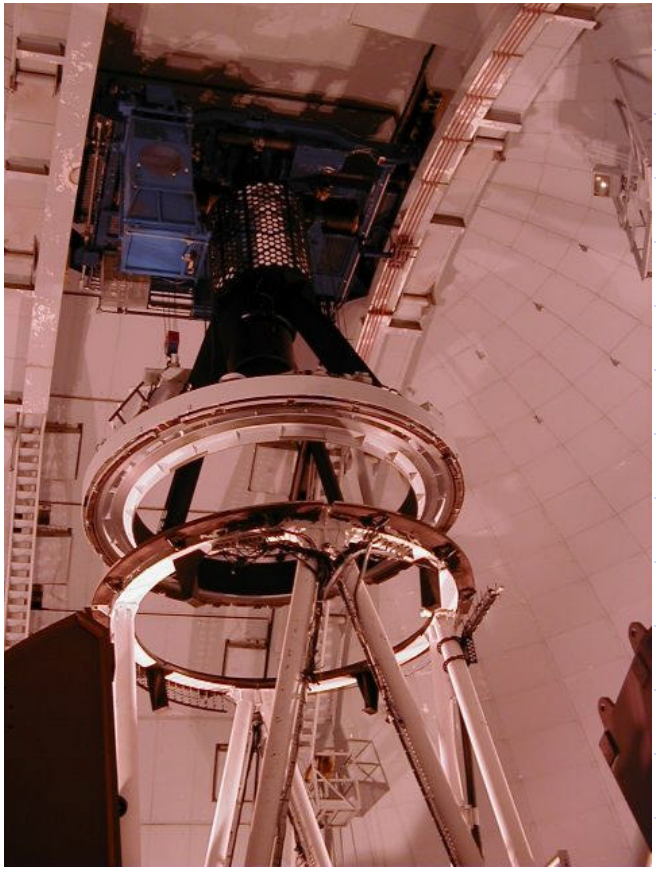
The Upper End

- The sheath bolted to the corrector and prime focus cage.



Mate upper end to telescope

- We will want to test this entire removable top end before shipping to Chile.



On to Observing

- The survey starts...

Changing the Way Astronomy is Done

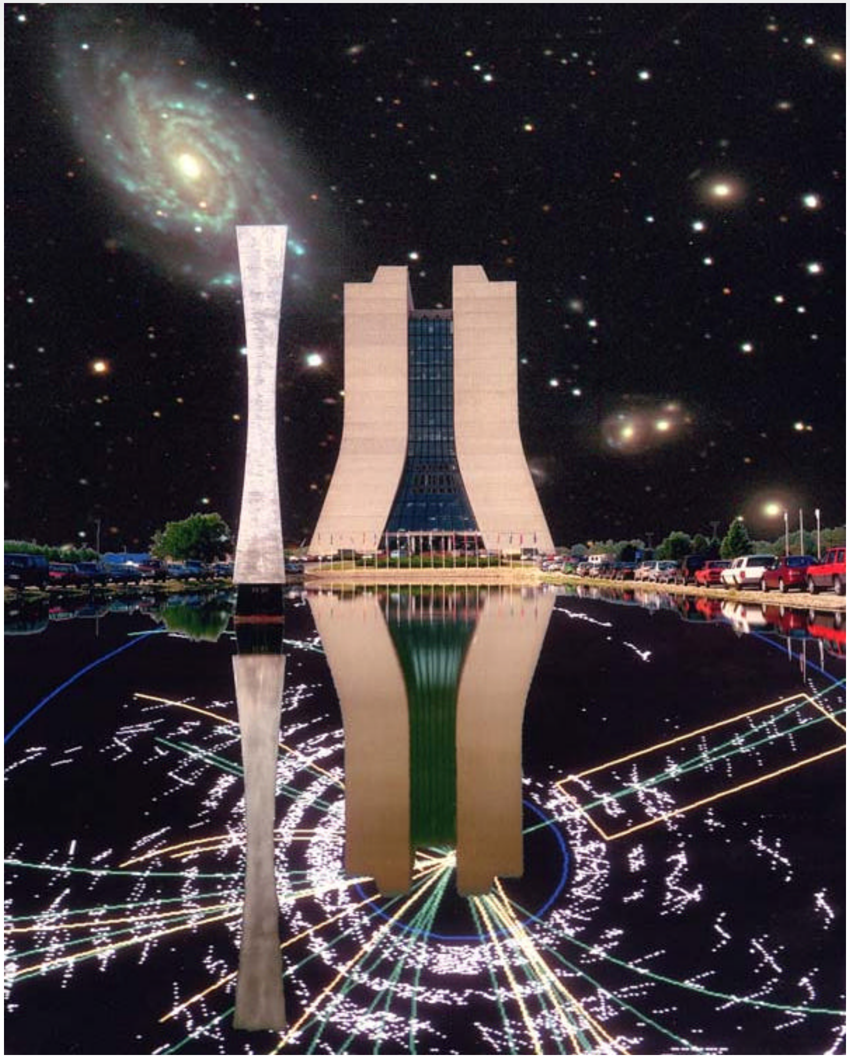
Surveys provide

The maximum amount of high-quality data

To the most scientists

For the lowest cost

To address the biggest problems of cosmology



Cluster Power Spectra

- **High bias of galaxy clusters enables accurate measurement of cluster P(k):**

  $\Delta k/k=0.1$? P(k) to 7% at k=0.1
  k<0.2 ? P(<k) to 2%

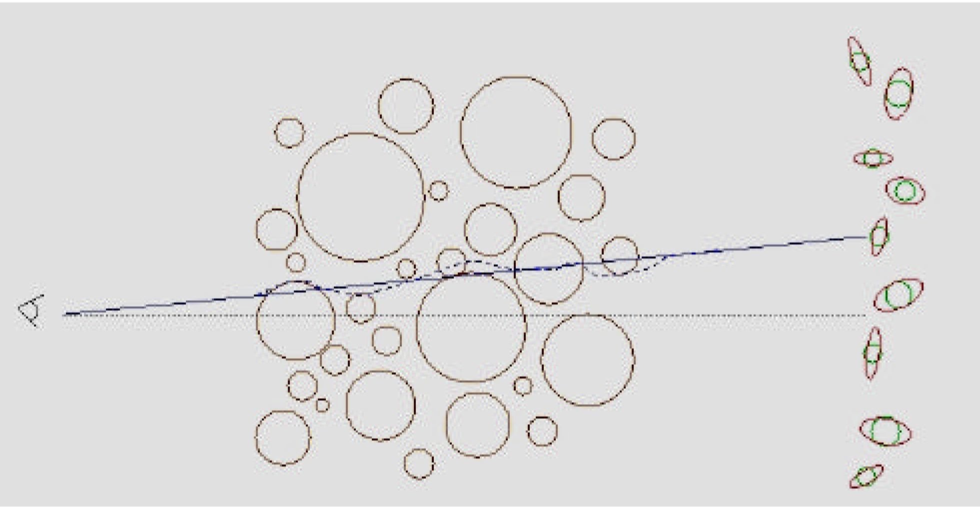
- **Expected statistical errors from 25,000 clusters:**

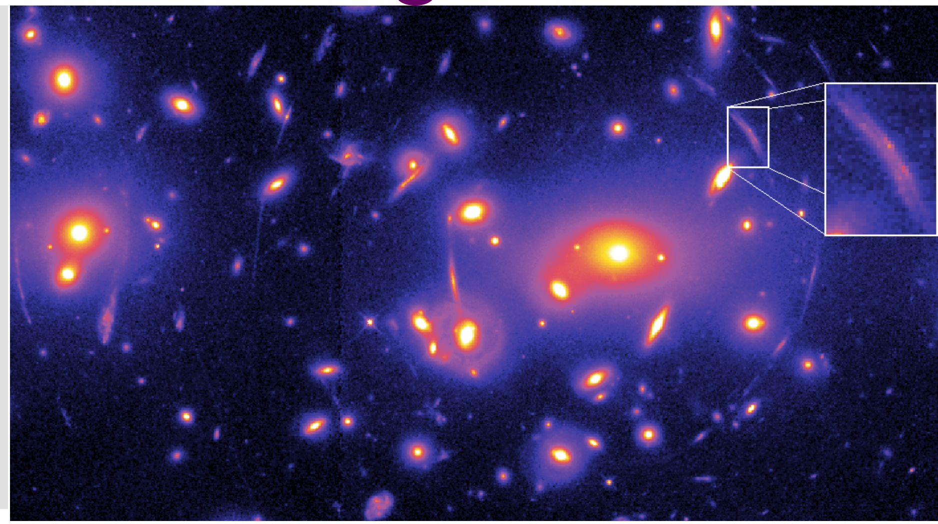
  Ω_M ~ to 0.013 - geometrical test
  w ~ to 0.04 - geometrical test
  $\Omega_\nu h^2$ ~ to 0.002 - usual shape test
  → **Combine with dN/dM** **(Majumdar & Mohr 2003)**

- **Noteworthy for survey planning**

  - baryon rings are useful: contain ~ half the information
    make test robust (CMB, β)
  - photometric redshift (0.01) sufficient to recover most of the info
  - including knowledge of bias would much improve constraints
  - z < 1 clusters are best complement to CMB

Weak Gravitational Lensing





Distortion Matrix: $$\Psi_{ij} = \frac{\partial dq_i}{\partial q_j} = \int dz\, g(z) \frac{\partial^2 \Phi}{\partial q_i \partial q_j}$$

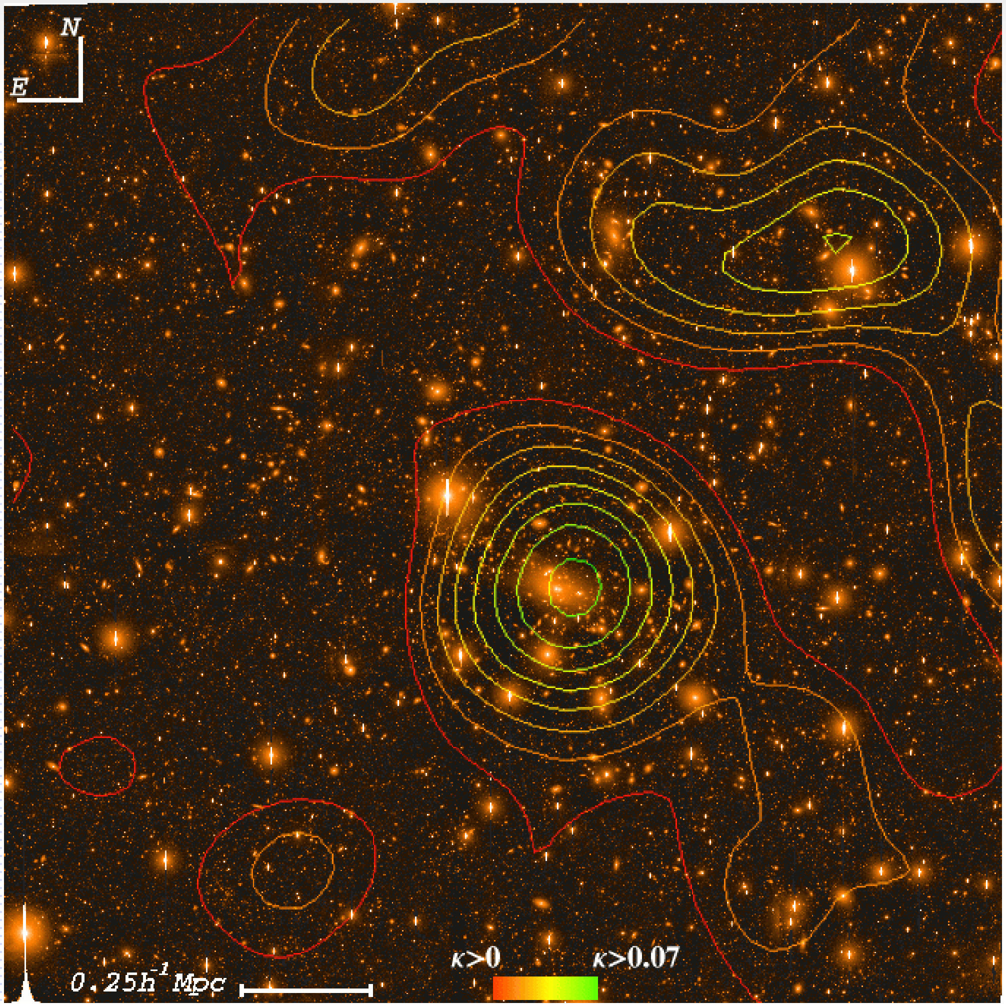
Theory

$\rightarrow$ Direct measure of the distribution of mass in the universe, as opposed to the distribution of light, as in other methods (eg. Galaxy surveys)

Weak Gravitational Lensing Of Clusters

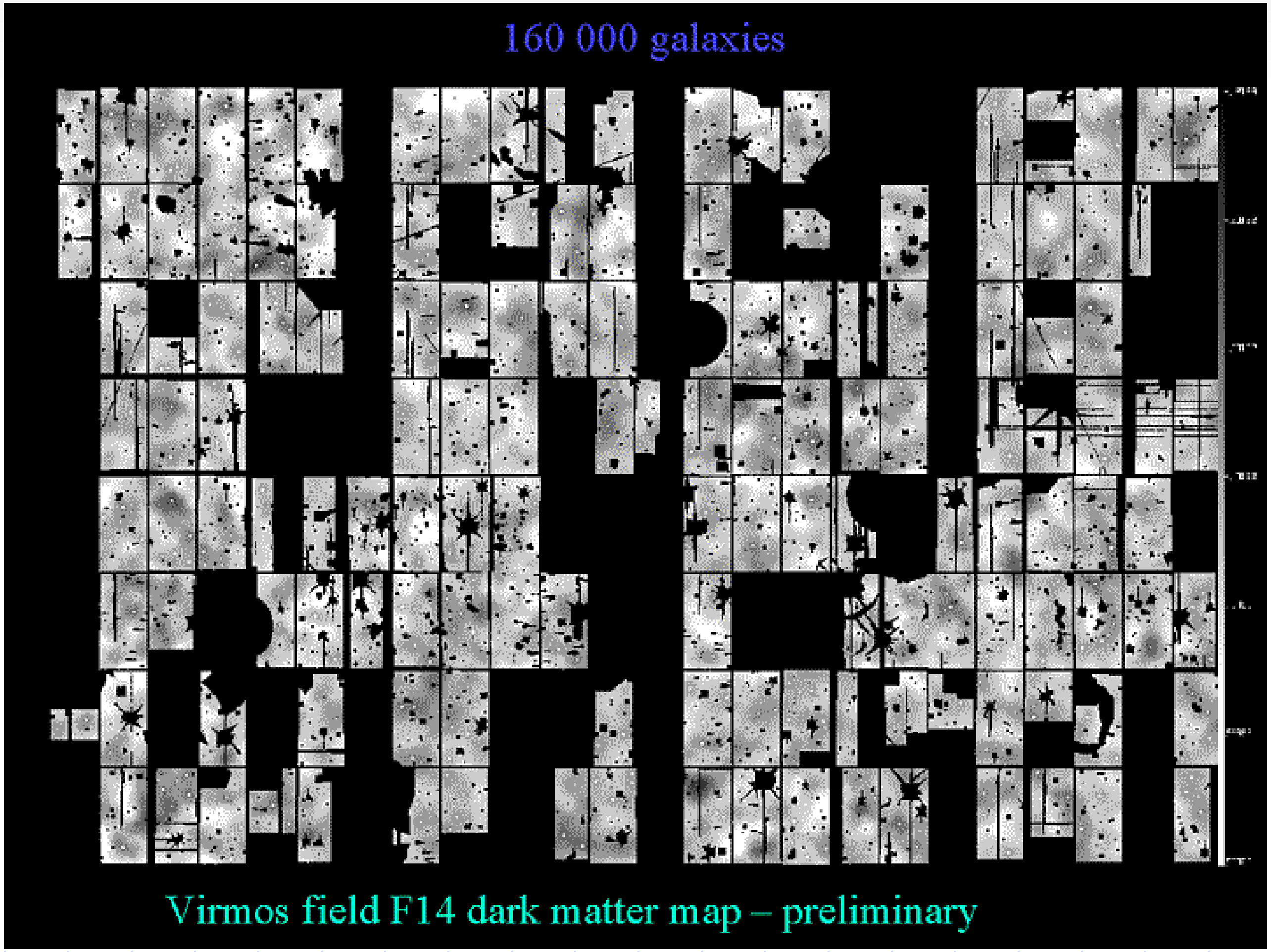
Abell
3667

z = 0.05

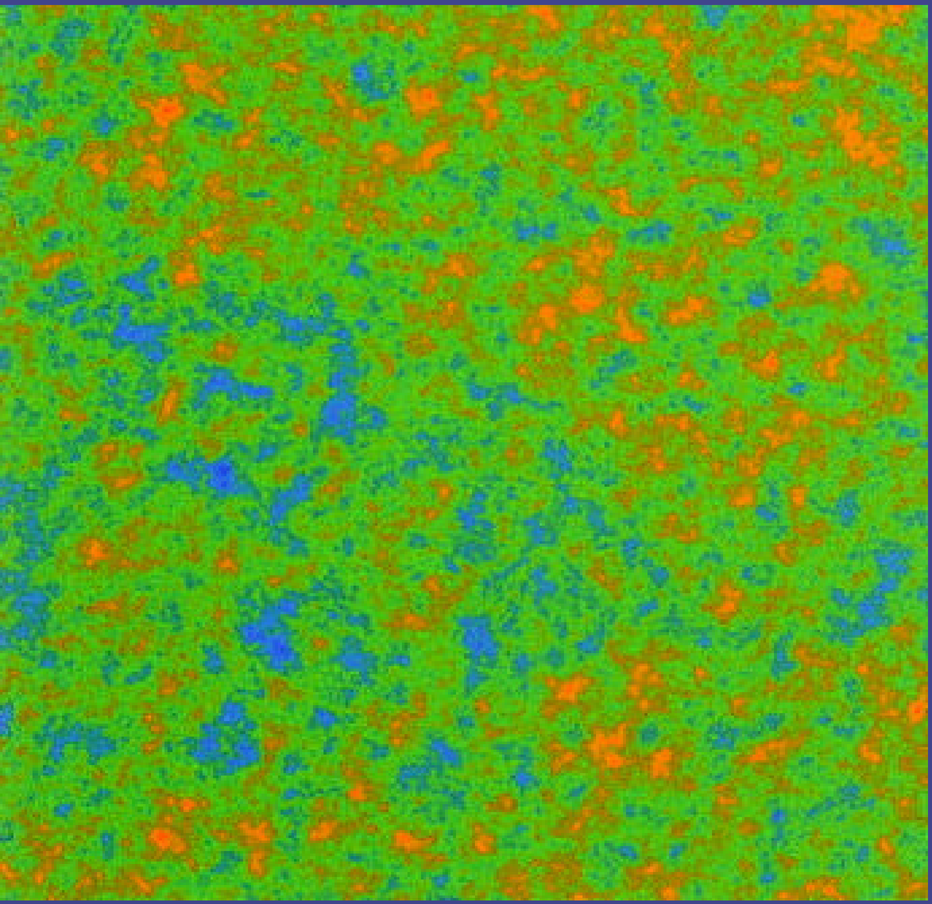


Joffre etal

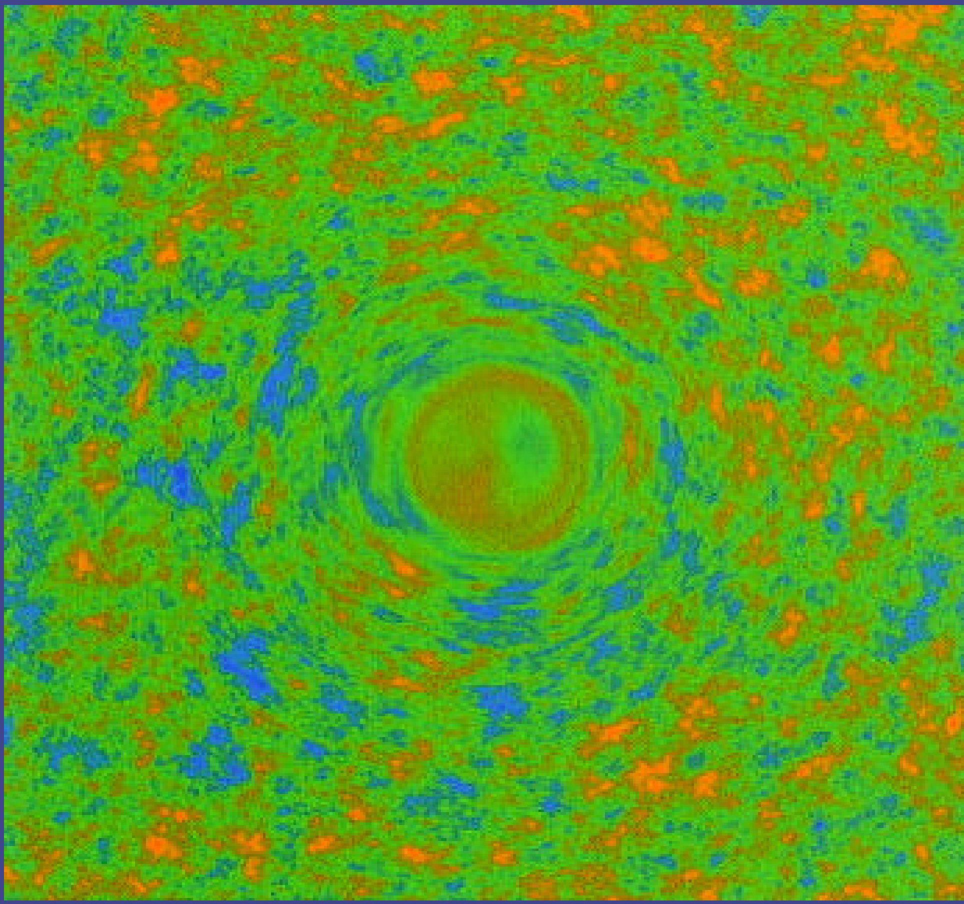
Weak Gravitational Lensing of Large Scale Structure



Weak Lensing in CMB



Temperature field



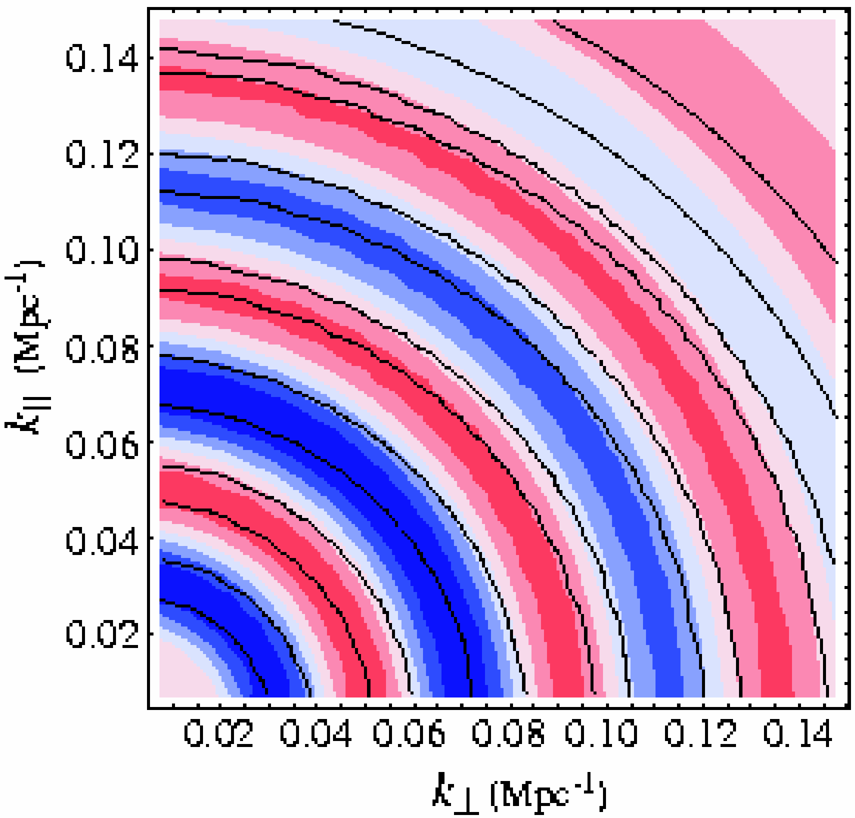
Lensed temperature field

Hu 2002

Acoustic Rings in 2D

A measurement possible with just the imaging data

Hu & Haiman (2003)



Power spectrum is measured at fixed angular scale and redshift.

Inferred spatial scales depend on the assumed cosmology

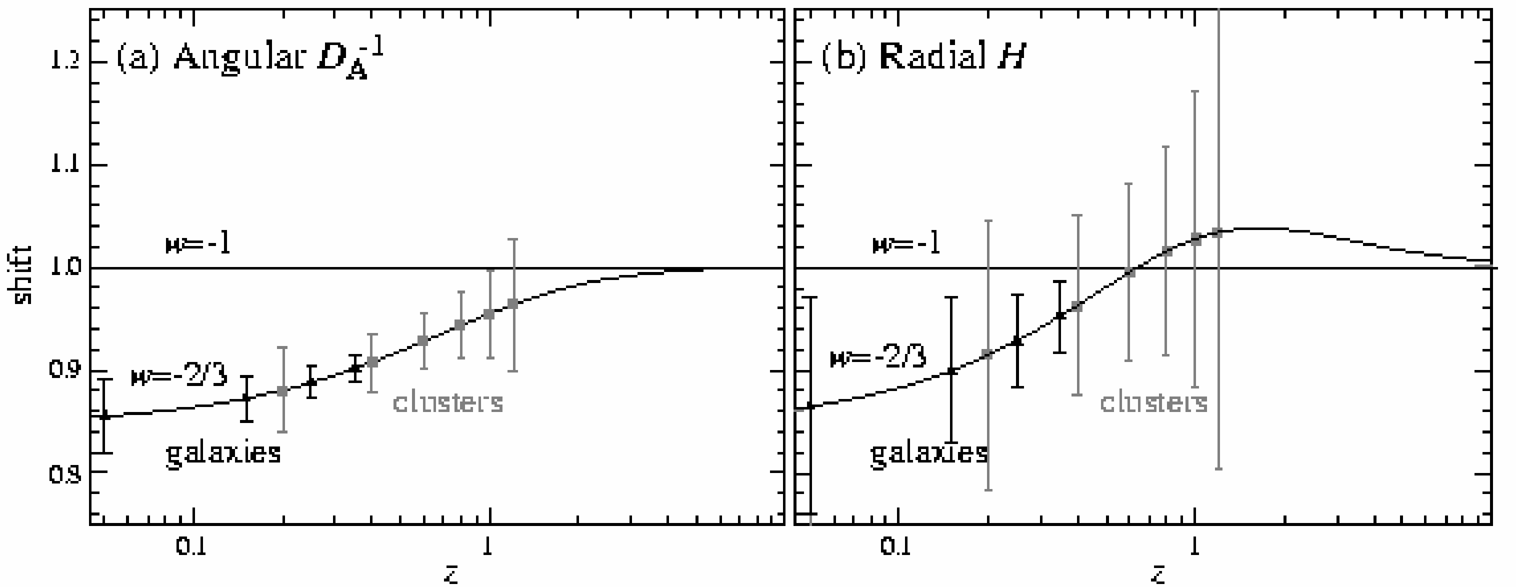
Forms purely geometrical test, if CMB priors are used

Insensitive to z-distortion

(c.f. Alcock-Paczynski test)

Errors on D_A (z) and H(z)

Hu & Haiman 2003



CMB priors

galaxies:	σ(w)=0.024	σ(Ω)=0.007
clusters:	σ(w)=0.040	σ(Ω)=0.013

Theorist's surveys:

Galaxies: 10,000 sq.deg

$M=10^{12.1}$ h^{-1} $M_?$ at 0<z<0.1 (SDSS main)

$M=10^{13.5}$ h^{-1} $M_?$ at 0<z<0.4 (SDSS LRG)

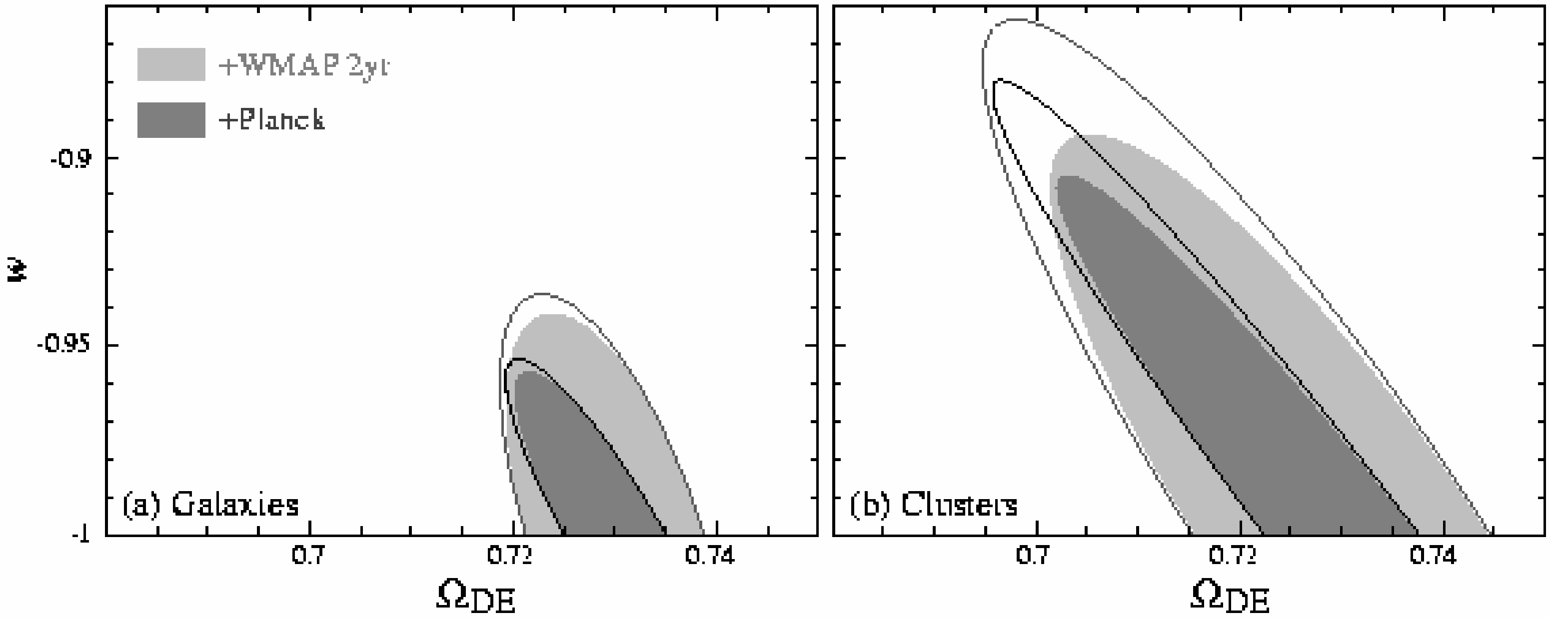
Clusters: 4,000 sq.deg

$M=10^{14.2}$ h^{-1} $M_?$ at 0<z<1.3 (SPT) - 25,000 clusters

Haiman

Errors on w and Ω_{DE}

Hu & Haiman 2003



Filled ellipses: b marginalized to an overall scaling
Empty ellipses: β, b marginalized (b separately in each Δz=0.1 bin)

galaxies:	σ(w)=0.024	σ(Ω)=0.007
clusters:	σ(w)=0.040	σ(Ω)=0.013

Haiman

Fermilab's Strengths

- Project Management
- Software System Design
- Data Processing and Distribution
- Pipeline Development
- Data Acquisition
- Mountaintop Engineering
- Calibration
- Analysis

We should add detector/camera construction!